

APPENDIX G

Support Technologies Descriptions

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The support technologies for short, medium and long-term deployment scenarios can be classified into several functional areas, including surveillance, communications, control strategies, traveler interface and navigation/guidance. The technologies in each category are described in detail as follows:

1. SURVEILLANCE

The purpose of surveillance is to obtain real-time operational information from the roadway network and from the vehicles along the network. This real-time operational information may be used for the following purposes:

- Congestion Measurement
- Locating an Incident
- Device Status
- Emissions Measurements
- Measurements for Transportation Planning Purposes
- Environmental (Weather) Measurements

1.1 Data Requirements

Traffic flow along a segment of roadway can be described in terms of the following parameters:

- Volume-a measure of traffic demand; the number of vehicles passing a point (i.e., detection zone) during a specified time period
- Occupancy-a measure of traffic density; the percentage of time that vehicles are present in the detection zone
- Speed-a measure of rate of motion of the vehicles (e.g., miles/hour); typically the average speed of all vehicles passing through the detection zone
- Average Vehicle Length-a method of classifying the different types of vehicles (by length) passing through the detection zone

These attributes can be used by the system to define the demand level, the utilization of capacity, potential incident (or other bottleneck) locations, and the level of service or performance of network segments. The information can be used also within system algorithms such as incident detection and travel time, and calculation of signal timing parameters. Additional traffic flow descriptors-such as vehicle locations and identification of roadway conditions, vehicle weight, and number of axles-may also be required by a system. These additional data may be appropriate for applications related to transit management, automated toll collection, and freight movements.

1.2 Technologies

Three types of data collection devices are available. These include:

- Static (roadway-based)
- Mobile (vehicle-based)
- Visual (use of live video cameras)

Table 1 examines the capabilities of each of these data collectors in terms of the technologies that are currently available or under development. A number of technologies will be incorporated into the Omaha Metropolitan Area ITS architecture.

1.2.1 Static Devices

Static devices can encompass in-pavement, overhead-mounted, and machine-vision technologies, as well as the roadway-based component of Automated Vehicle Identification (AVI) systems. Examples are discussed briefly below.

In-Pavement Detectors

The most common of this type is inductive loop detection, which has been the predominant form of surveillance technology for almost 30 years. Loop detectors consist of a electronically-tuned loop of wire buried in the roadway. Detections of vehicles occur when each vehicle passes over the loop, thus decreasing the inductance during the interval. Loop detector reliability is often a function of design, installation and weather conditions. Improved sealants, loop-wire casings, and embedded pre-formed loops, while more expensive, are also more reliable.

Other in-pavement detectors include magnetic detectors and piezometric devices. The California Department of Transportation (Caltrans) has conducted a demonstration test of the use of the loop detector's electronic field as a radio transmitter, such that roadway congestion information can be transmitted to vehicles equipped with low-power receivers and in-vehicle displays.

Overhead Detectors

Installation of the detection unit above or to the side of the roadway permits maintenance activities to be performed with minimal disruption to the traffic flow. Moreover, these overhead-mounted detectors can generally remain operational during roadway reconstruction and rehabilitation activities that usually destroy loops and other in-pavement devices.

One potential drawback with these technologies is that their optimum placement is (typically) directly over each lane; and for such an installation to be cost-effective, an existing overhead structure (e.g., overpass, sign support, etc.) is required. The location, spacing, and placement of these existing structures can impact the effectiveness of the surveillance subsystem. Another concern is that most of these technologies have not been completely provided in terms of accuracy or long-term reliability. However, operational tests involving many of these surveillance technologies, plus an FHWA-sponsored research effort to field test and evaluate these detectors, are underway. It is anticipated that many of these devices will be viable and proven candidates for ITS-based systems in the short term.

TABLE 1

MONITORING/DETECTION TECHNOLOGIES

Type	Technology	Observable Data	Mounting	Cost	Installation*	Reliability*	Accuracy*
Static	Inductive Loops	Counts, Presence, Occupancy (Speed, Density, Axles w algorithms)	Embedded in road	Low-medium	Moderate	Moderate	Medium-High
	Piezoelectric	Counts, Speed, Weight	Overhead or side of road	Low	Simple	High (est.)	High
	Radar	Counts, Presence, Occupancy, Speed, Density	Overhead or side of road	Low	Simple	Moderate (est.)	Medium-High
	Passive Infrared	Counts, Presence, Occupancy, Density	Overhead or side of road	Low	Simple	Moderate (est.)	Medium-High
	Active Infrared	Counts, Presence, Occupancy, Density	Overhead or side of road	Low	Simple	Moderate (est.)	Medium
	Acoustic (audible)	Counts, Presence, Occupancy, Density (Speed with multi-sensors)	Overhead or side of road	Low	Simple	High (est.)	Medium
	Ultrasonic	Counts, Presence, Occupancy, Speed, Density	Overhead	Low	Simple	Moderate (est.)	Medium-High
	Video Image Processing (VIP)	Counts, Presence, Occupancy, Density, Length, Detect Incidents	Overhead or side of road	Medium-High	Simple	Moderate (est.)	Medium
Mobile	Magnetic	Counts, Presence, Occupancy, Density (Speed with multi-sensors)	Embedded in road	Low	Simple	Moderate (est.)	Medium
	AVI (Bar Code)	Weight, axle, other identification or dynamic information	Road:	Low	Low	Low	Moderate-High
	AVI (Inductive Loop)	Weight, axle, other identification or dynamic information	Reader on side of road	High	Moderate	Moderate-High	Moderate-High
	AVI (Microwave or RF)	Weight, axle, other identification or dynamic information	Embedded in road	High	Low	High	Moderate
	AVI (Surface Acoustic Wave)	Weight, axle, other identification or dynamic information	Reader on side of road	Medium	Low	Moderate	Moderate
	AVI (Image Processing)	Read License Plates/IDs	Overhead or side of road	High	Low	Moderate	Moderate-High
	AVL (Sign Post)	Speed, Direction, Location, ID, Dynamic Info	Radio transmitter, side of road	Low	Low	N/A	N/A
	AVL (Loran C)	Speed, Direction, Location, ID, Dynamic Info	Centralized transmitters	Low	Low	N/A	N/A
Visual	AVL (Dead Reckoning)	Speed, Direction, Location, ID, Dynamic Info	Transmitters, side of road	Low	Medium	N/A	N/A
	w/ Digital Map Position	Speed, Direction, Location, ID, Dynamic Info	Single satellite	Low	Medium	N/A	N/A
	w/ Satellite Correction	Speed, Direction, Location, ID, Dynamic Info	Microwave to multiple satellites	Low	High (GPS)	N/A	N/A
	AVL (Global Positioning Satellite)	Speed, Direction, Location, ID, Dynamic Info	Centralized Transmitters	Medium	Low	N/A	N/A
	AVL (Radio/Multiple Access)	Speed, Direction, Location, ID, Dynamic Info	Caused by travelers, Readers at Transit Vehicles, Toll Collection Facilities, other sites	Medium	Medium	N/A	N/A
	Smart Cards	Rider ID, Origins, Destination based on transit location					
	Closed-Circuit Television (CCTV)	Qualitative observation of flows, congestion, incidents	Overhead or side of road, portable	Low-Medium	Low-Medium	Moderate-High	N/A
	Stationary Camera	Photograph specific vehicles, license plates	Overhead or side of road	Low	Low	N/A	N/A

1. Cost = Low (<\$10k), Medium (\$10k-30k), High (>\$30k)

2. Field Installation = Simple (minimal field construction), Moderate (Limited Conduit), Extensive (New Conduit, Complex Communication and Software Requirements)

3. Reliability = High (>1 year MTBF), Medium (8 months-1 year MTBF), Low 9<8 months MTBF), N/A (Not Applicable or Not Available)

4. Accuracy = High (measures most vehicles and data), Low (measures some vehicles and data), N/A (Not Applicable or Not Available)

Devices of these types are presented below:

Radar Detectors direct a continuous wave of low-power microwave energy toward an area of roadway at a 45 degree angle. As vehicles pass through the beam, the energy is reflected back to the sensing element which measure the speed based on the Doppler effect. Wide-beam radar detectors provide the capability of counting a full approach or roadway, while narrow-beam detectors are used per vehicle lane.

Microwave Detectors are very similar to the radar detectors in that they transmit microwave energy toward an area of roadway from an overhead-mounted device. Instead of measuring a vehicle's speed using the Doppler effect, the microwave detector measures the time it takes for a transmitted pulse to arrive at the road or a vehicle, then be reflected, and return to the detector. The presence of a vehicle is denoted by the difference in the time of arrival of the pulse when a vehicle passes through the field of view, as compared to the time of arrival of the pulse from the road surface. The detectors can either be side-mounted or in the roadway. The later is especially useful for lane-specific data collection, since large vehicles would not interfere with measurements of vehicle movements behind. However, this configuration is also more costly.

Ultrasonic Detectors include an overhead-mounted transducer which transmitters sound waves (at a selected frequency between 20 and 65 KHz) into an area defined by the beam width pattern of the transducer. The detector transmits a pulsed waveform and measures the time it takes to measure the height profile of a vehicle, thereby providing classification data in addition to volume and occupancy.

Infrared Detectors currently marketed consist of both active and passive models. In the active system, detection zones are illuminated with low power infrared energy supplied by light emitting diodes (LEDs) or laser diodes. Real-time signal processing techniques are used to analyze the received signals and to determine the presence of a vehicle.

The passive infrared detector measures similar traffic parameters! It uses an energy sensitive detector element to measure the change in energy emitted when a vehicle enters the field of view. The source of this energy is blackbody radiation due to the non-zero temperature of emissive objects.

Several disadvantages of infrared detectors are often cited. Changes in light and weather will cause scatted of the infrared beam and received energy. Their reliability in high traffic flow conditions has also been questioned.

Passive Acoustic detector "listens" for vehicles as they pass through a detection zone-specifically, identifying the unique acoustical signature of engine noise or tires on the pavement. This is a very new detector technology with no installations as of yet.

Video Image Processing Systems (VIPS)

VIPS technology uses microprocessor hardware and software to analyze "video" images of the roadway, and to extract real-time traffic flow data (e.g., volume, occupancy, speed, classification, etc.). With current VIPS systems, "pseudo-detectors" are identified within the camera's field-of-vision by the user. Every time a vehicle enters or crosses this detection zone, a detection signal (i.e., presence) is generated which can then be processed to provide volume, speed, classification, and occupancy measurements.

VIPS offers several advantages-it does not require installation in the pavement, and multiple detection points covering several lanes can be defined within a single camera's/sensor's viewing area. Potential concerns with VIDs are summarized below:

- Night measurements (occupancy and classification not possible except with low-light sensitive cameras or where area is very well lighted).
- VIPS camera placement may result in occlusion-when the image of one vehicle partially or completely masks the image of an adjacent vehicle. Cameras are to be mounted high above the roadway and at an angle such that this is minimized.
- Cannot combine VIPS with CCTV camera functionality. When a CCTV camera is panned, tilted, or zoomed to view an incident or other congestion-the pre-set detection zones are lost.
- The cost of a VIPS system-the camera, microprocessor, interconnecting cabling-is very expensive relative to other detection technologies. The average cost of a single VIPS installation is \$40,000-\$50,000.

VIPS is rapidly becoming a "proven technology", with system now being marketed by several vendors, and recent tests showing vehicles detection accuracy in excess of 95 % . It is anticipated that future VIPS will provide greater functionality, including tracking individual vehicles, measuring speeds directly as an output of the vehicle tracking process (as compared to the current method of emulating loop pairs), and identifying congestion and incidents.

Detector Data Processing

A major issue concerns how and where the data from the roadway detectors are processed. The key consideration is flexibility. Given the rapidly changing detector market, an ITS-based system must be capable of measuring traffic flow utilizing several different detector technologies, while also providing this real-time information to the control center in a single, standard format. In this manner, the system is not locked into a specific technology or vendor. New detector processing at central remains consistent.

Most roadway management systems process the data in the field, and then transmit the data to the control center using a single system-wide format. The detector data processors can be any microprocessor form, including Type 170 controllers installed at each detector station. Firmware provided for the processors typically accomplish the following processing tasks:

- Accumulate traffic flow measurements and compute other parameters from each detector over a specific time period (e.g., 20 seconds to 1 minute).
- Perform initial error checking of the data (e.g. , comparing the accumulated flow measurements to user-defined over- and under-thresholds).
- Format the preprocessed detection station data and error codes for transmission to the control center. The central computer polls each detector station once every time period, which responds with the accumulated traffic measures. The data format should be consistent between stations, and should include the following information, as appropriate:

- detector station identification
- volume by lane (actual count)
- occupancy by lane
- average speed by lane
- average vehicle length by lane
- cumulative volume by lane (vehicles/hour)
- percent occupancy by lane (percent)
- cumulative average speed by lane (MPH)
- smoothed average volume for mainline (vehicle/hour)
- smoothed average occupancy for mainline (percent)
- smoothed average speed for mainline (percent)
- smoothed average vehicle length for mainline
- detector failures

1.2.2 Mobile Devices

Three types of mobile devices are discussed in the following:

Automatic Vehicle Identification (AVI)

Automatic vehicle identification (AVI) provides electronic reading and recording of a vehicle's identity as it passes specific points, without requiring any action by the driver or an observer. Information that identifies a vehicle is encoded onto a vehicle-mounted transponder' (or toll-tag). As the vehicle passes a site with an AVI antenna/reader, the tag is activated to transmit the coded data to the antenna, and then to an adjacent roadside reader or processor. Several different technologies and procedures are used in AVI systems, for example:

- Tags may be bar coded, and then scanned using optical lasers or infrared. The most versatile systems using RF or microwave transmissions to energize and read the encoded tag.
- Antennas can be mounted above or to the side of the roadway, while some systems utilize an inductive loop embedded in the roadway as an antenna. The antenna mounting obviously impacts the placement of the vehicle tag.
- Some AVI systems are "read-only", while other provide two-way data transmission between the reader and the tag (e.g., the reader can also transmit data to the tag which is encoded in a "scratch pid" for subsequent reading by a downstream antenna).

The primary applications for AVI are to automate toll collection without stopping (known as electronic toll collection-ETC); automatic equipment identification to identify rolling stock and inventory assets (e.g., rail cars, highway trailers) in the rail, shipping and motor freight industries; for truck weight and safety enforcement regulation; and for commercial vehicle revenue collection and curb usage regulation at airports.

Nationally, over 100 million electronic toll transactions annually are now processed automatically via electronic toll collection. Electronic toll collection enables roughly three times as many transactions per lane per hour as is currently done with manual toll collection. Therefore, traveler delays (and air

pollution) can be significantly reduced, along with a concomitant reduction in the labor resources needed for toll payment transactions.

Another ITS-related use of AVI involved commercial vehicle operations. An example of this application is the Crescent/HELP (in California along I-5 north of Los Angeles and I-10 east of Los Angeles) projects, in which AVI will be implemented. Certain trucks will be equipped with identification transponders or tags, which can be read at highway speeds to automatically identify the vehicle as to weight, credentials and appropriate certifications.

Currently, two separate national groups are addressing AVI standardization issues. Reaching an acceptable consensus for these standards will not be easy, and will likely take considerable time. In the meantime, regional entities such as TCA and Crescent/HELP are proceeding on independent courses.

Smart Cards

Smart Cards are similar in principle to a bank ATM card, but smart cards offer many more capabilities in that they function as portable minicomputers, containing both microprocessor and memory elements. Smart cards may be used by travelers to board transit vehicles and to pay tolls, parking fees, and cab fares without cash because the necessary identification and billing information is automatically read from the card. Smart cards may also be used to identify origins and destinations of passengers by using a reader system mounted at entry and exit doors. Other applications can include vehicle maintenance, driver management, and fleet management. The applications of smart cards in the Omaha Metropolitan Area will include fare payments on transit vehicles.

Automatic Vehicle Location (AVL)

Automatic Vehicle Location (AVL) systems have three basis elements:

- location determination
- communications for reporting vehicles' location to a central facility (typically a dispatcher)
- displays of vehicle's location at a central site and elsewhere on an information network

Real-time information regarding vehicles' locations and progress may be utilized in ITS-based systems to track schedule adherence of transit and commercial vehicle fleets, thereby improving vehicle response times; to provide transit information (e.g., expected arrival/travel times) to travelers at bus stops, transfer points, and at home/office; to enable the optimum selection of dispatched vehicles; to improve safety of personnel and cargo (via operator-activated/automated MAYDAY alarms); to indicate roadway and traffic conditions (i.e., vehicle probes); and to generally improve the efficiency of fleet operations and management.

Several AVL-based systems are on the market. These include devices used primarily for transit management as well as for tracking stolen vehicles. An AVL system can also be utilized for tracking of Freeway Service Patrol (FSP) vehicles.

AVL tracking utilizes a number of vehicle-roadway communication and location techniques.

To summarize the use of AVI and AVL as vehicle probes for traffic management and information, a number of issues are to be considered:

- Population of AVI-tagged or AVL-equipped vehicles. In the short term, it is expected AVI will be utilized for toll collection and for private fleet management. AVL will be initially focussed on transit vehicles as well as fleet management for Freeway Surveillance Patrol and other government vehicles.
- Reader Spacing - for AVI, it is assumed that one-mile reader spacings will be required.
- Information ascertained from AVI and AVL for traffic information use. At the minimum, it is expected that reader location, time and vehicle ID will be the data obtained from AVI, and location coordinated, time and vehicle ID will be obtained from AVL. Knowledge of personal information associated with vehicle ID must be kept in confidence such that an individual's right-to-privacy is not violated.

1.2.3 Visual Devices

Closed-circuit television cameras have been used extensively in traffic management systems for roadway surveillance. Figure 1 illustrates a sample CCTV installation. In addition to its primary task of incident verification, CCTV may also be used for other surveillance functions in corridor management, including:

Freeways

- Monitoring traffic movements on the mainline, HOV lanes, and the entrance/exit ramps (e.g., driver response to various CMS messages, CMS message verification and fine tuning, HOV shoulder lane usage, compliance with ramp metering, etc.).
- Confirm the existence of a suspected incident that has been detected through other means, determine its nature and the appropriate response.
- Identify and detect stranded motorists.

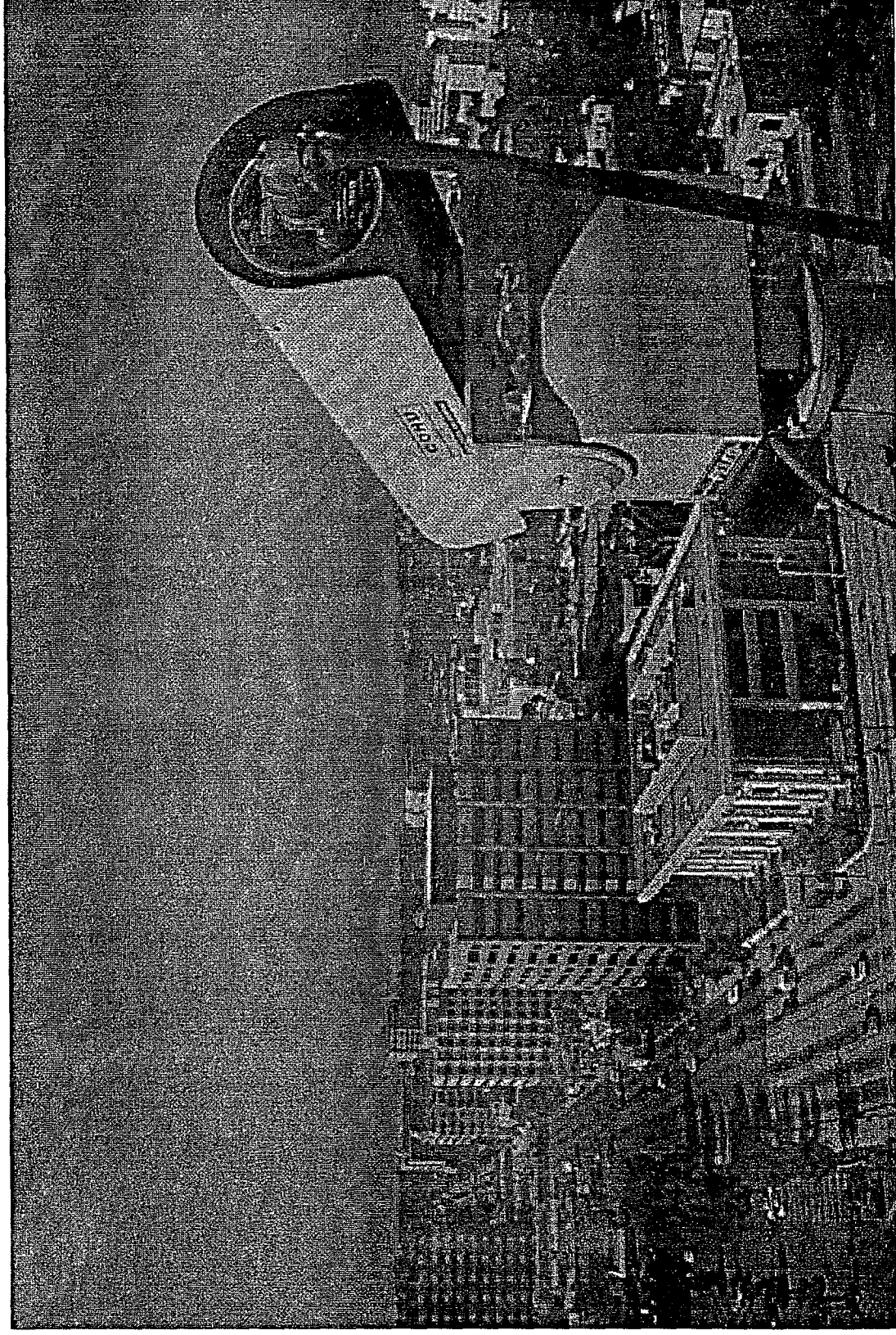
Corridors

- If cameras overlook parallel surface streets, verifying that the local street system has operating capacity before implementing freeway diversion, and then monitoring system performance as diversion occurs.

Surface Streets

- Monitoring the operation of critical signalized intersections and evaluating the signal timing and related functions .

Omaha Metropolitan Area ITS EDP Study



CCTV

Figure 1

General

- Weather/hazardous condition observations
- Identify damage to system field equipment resulting from contractors, accidents, storms, etc.

It is noted that the principal purpose of CCTV is not to identify the occurrence of or congestion conditions of an incident-it has been found that simply monitoring the video images does not result in early detection.

A major issue associated with the design of a CCTV surveillance subsystem is determining the appropriate coverage. Roadway segments requiring full CCTV coverage (i.e., no “blind” spots) generally experience high volume/capacity ratios and a high frequency of incidents. Full coverage is also useful during roadway rehabilitation and reconstruction activities. Current camera technology allows relatively clear viewing of 1/2 mile in any direction, which translates to a nominal one-mile spacing between cameras on tangent. Closer spacings will likely be required, however, to overcome obstacles such as horizontal and vertical curves, extended overpasses/tunnels, and to improve the viewing of areas of specific interest. For those sections where full CCTV coverage is not required or cost-effective to install, cameras may be installed at key locations such as interchanges and congested intersections.

1.3 Other Surveillance Technologies

1.3.1 Weather/Environmental

Several manufacturers offer in-pavement climate sensors which can provide the following real-time information:

- Surface temperature
- Surface condition such as dry, moist (dew), wet, wet with salt, ice (freezing alert)

These climate detectors are widely used at airport facilities to monitor runways. In a roadway ITS application, the road surface information could be utilized for adapting the traffic management and control strategies (e.g., incident detection calibration factors, ramp metering rates) and for tailoring the traveler information (e.g., “ICY CONDITIONS AHEAD”) to better suit the particular conditions.

As another example, LIDAR, which stands for Light Detection And Ranging, is an optical technology that may be used to measure air quality. LIDAR can define the location of a cloud of particles in a beam of light. These particles may be smog or water molecules. LIDAR can operate in the infrared or ultraviolet portions of the spectrum, or by using two laser wavelengths (DIAL - Differential Absorption Lidar). Such detectors may be used to process basic air quality measures and produce reports relating air quality to traffic flow conditions and ITS strategies.

In the Omaha area, NDOR uses a “SCAN” system allowing access to radar weather information. There are a number of “weather” data collection stations throughout the roadway system. These are integrated with stations from the City and airport. SSR of St. Louis provides “on-line” information to all parties. The SCAN system has been in operation for five years. There are currently two stations capable of

“color imaging”. NDOR has expressed interest in expanding the number of weather stations which cost approximately \$50,000 to \$70,000 per station.

1.3.2 Manual Call-In

Incident management can be obtained directly through call-in procedures. In the Omaha Metropolitan Area, these can include call-ins to HP from “Cellular 911” (in-vehicle cellular phones). The ITS traveler information function should provide the capability of access to incident location and type information for development of coordinated traffic response strategies, particularly for major incidents which are blocking lanes.

2. COMMUNICATIONS

Communications links include the following:

- Links within Infrastructure (Central-to-Central, Central-to-field, field-to-field)
- Infrastructure-to-vehicle

This section will focus on communications links within the infrastructure. The infrastructure-to-vehicle links are discussed in greater detail in the Navigation/Guidance section.

The most important consideration in designing a large communications network is that to be economically viable, it must provide reliable service for 20 years or more. At this period in the communications industry, the extent of technological change, standards development and market restructuring presents a considerable challenge in identifying appropriate technologies.

The ITS architecture will require the capability of transmitting data, voice and video. Presented below is a summary of enabling technologies in communications which will contribute to the ITS architecture defined in other sections of the report.

2.1 Data and Voice

Data and voice transmission technology is now virtually all digital and largely based on the T-carrier system and the synchronous optical network (SONET) standards in both public and private networks. In addition to transmission speeds, these standards also address chassis and racks, plug-in boards, interface, and connectors. This generally allows a second manufacturer’s equipment to be added to a give site without re-configuring the hardware. Moreover, several capable “network management” tools have been developed to support the T-carrier and SONET electronics. In addition to these “high speed” networks, another network protocol being adopted on a larger scale is the Integrated Service Digital Network (ISDN), which consists of 64-144 Kpbs channels, equivalent to one-fourth of a T-1 channel.

2.2 Video Transmission

Video images from CCTV cameras to a control center place the heaviest load on the communications network. Specifically, full-motion video requires 6 MHz (megahertz) of bandwidth per camera, as compared to a bandwidth requirement of only 0.005 MHz for a low-speed (1200 baud) data channel. Another consideration is that video is an analog source, while data communication and the T-carrier and SONET Standards are digital. Accordingly, video transmission has typically been the most problematic element of communications network (and system) design.

Video transmission is best done over wide-band technologies utilizing dedicated microwave frequencies, coaxial cable, and optical media (fiber optics). Developments have included fiber optic video multiplexers (which provide up to 36 video images over a single fiber), and fiber optic transmission equipment which permit analog video and digital camera control data to be transmitted over the same fiber.

In some cases, however, the cost of new cable and conduit for video may be prohibitive. An alternative is the use of digital data/voice media along with the means to “compass” the analog signal into a digital format. A coder-encoded (CODEC) unit can digitize the video image and compress the bandwidth such that the real-time picture may be transmitted over the telephone lines-as well as other data communications media (e.g., radio, satellite)-to another CODEC unit where the digitized information is converted back to an analog format for viewing on a television monitor. A reasonable degree of “full motion” (e.g., 10-30 frames per second) and resolution is maintained, even when there is significant motion in the video image, or the camera is being panned and tilted. The best video quality is associated with the highest transmission rates (typically 384 kilobytes per second or higher).

The most significant trade-offs with digitized video vs. analog video involve quality (full motion video tends to be higher quality and less “jumpy”) as well as the cost of CODECs. Multi-channel CODEC’s for trunk transmission of several channels are expensive (\$40,000 each end) and require environmental video enclosed including heating and air conditioning. Single channel CODECs are less expensive, but are suitable for small numbers of cameras only.

2.3 Communication Media

At the heart of any communications subsystem is the transmission medium. Each communications medium has inherent characteristics such as frequency response and bandwidth, susceptibility to interference and noise, allowable baud rate, repeater requirements, and physical constraints, which determine its suitability for use in the Omaha Metropolitan Area ITS architecture. These technologies are discussed below and summarized in Tables 2 and 3.

TABLE 2
S-Y OF COMMUNICATION OPPORTUNITIES

	Media	Advantages	Disadvantages
1.	Twisted Pair	<ul style="list-style-type: none"> - Ease of use - Inexpensive - Easy to repair 	<ul style="list-style-type: none"> - Susceptible to EMI - Low data rates - Short distances - Data only
2.	Coaxial	<ul style="list-style-type: none"> - Higher data rates than twisted pair - Longer distances than twisted pair - Good for video and data 	<ul style="list-style-type: none"> - Short and medium distances - Moderate data rates - Susceptible to EMI
3.	Fiber Optic	<ul style="list-style-type: none"> - Not susceptible to EMI - High data rates - Long distances - Cable has greater future potential capacity than other technologies - Becoming cost effective - Good for video and data 	<ul style="list-style-type: none"> - Higher installation/repair costs
4.	Microwave/ Infrared	<ul style="list-style-type: none"> - Wireless - no cable plant or conduit required - Good for video and data 	<ul style="list-style-type: none"> - Subject to atmospheric interference - Requires line-of-sight path - Lacks capacity - May need antenna site
5.	Radio (Spread Spectrum)	<ul style="list-style-type: none"> - Wireless - no cable plant or conduit required 	<ul style="list-style-type: none"> - Availability of service during peak network usage cannot be guaranteed - Not economical for outstation equipment which must be regularly polled - Not a proven technology
6.	Radio (Cellular)	<ul style="list-style-type: none"> - Wireless - no conduit required - Low cost application - Proven technology 	<ul style="list-style-type: none"> - Available only on a dial-up basis - Requires line-of-sight path
7.	Radio (Packet)	<ul style="list-style-type: none"> - Wireless - no conduit required - No line-of-sight required - Low cost application 	<ul style="list-style-type: none"> - Limited to a range of approximately 10 miles

TABLE 3

COMMUNICATIONS MEDIA COMPARISON

Medium	Cost*	Additional Construction Cost Per Mile (includes conduits)	Applications			Maintenance and Training Requirements	Comments
			Data	Video	Voice		
Fiber Optics	\$40,000	\$135,000	X	X	X	Medium	Most flexible medium
Leased Lines	\$95,000 implementation \$4,000 annual lease	N/A (Leased)	X	C	X	Low	Quickest medium to implement
Twisted-Pair Cable	\$15,000 per mile	\$135,000	X	C	X	Low	Proven as a data/voice carrier. Limited video use
Spread Spectrum Radio	\$15,000 per hop	N/A (Wireless)	X	X	X	High	New application unproven for technology. FCC licensing not required.
Microwave	\$30,000 per hop	N/A (Wireless)	X	X	X	High	Needs FCC licensing, frequency.
Satellite	\$80,000 annual	N/A (Leased)	X	C	X	High	Needs FCC licensing, frequency. Requires compression of video.
Cellular Radio	\$45/month \$0.50/minute Airtime charges	N/A (Leased)	F		X	Medium	High costs for dedicated use, digital cellular transmission not yet implemented. High usage causes potential reliability problems.

* 1. For Fiber Optics, add approximately \$30,000 total for end equipment. Other media include end equipment in cost.
2. Leased and Wireless Media Costs are per link and include video transmission equipment.
3. Number of hops requires for Spread Spectrum and microwave are topography-dependent.
4. Costs referenced are per recent JHK projects in Anaheim and San Jose, CA, plus Draft Communications Handbook for Traffic Control Systems, FHWA, 1992.

2.3.1 Fiber Optics

The application of fiber optic cable to traffic signal control systems is relatively recent, however, it has been used in several systems with great success. Fiber optic technology uses pulses of light sent through a long thin glass tube. This technology can accommodate very large amounts of communications at very high speeds with low error rates.

Multiplexing in fiber optic is typically achieved via TDM, however, TDM is achieved on a bit-by-bit basis as opposed to the message-by-message technique used in twisted pair cable. An alternative method for providing multiple channels in fiber optic communications is to provide multi-fiber cables. This method is more common, easier, and often more cost effective by eliminating the expensive sophisticated multiplexers.

Fiber optic cable is immune to electromagnetic interference, however, some attenuation does occur. As the light travels down a length of fiber, it broadens or spreads, the fiber optic equivalent of noise. This spreading can cause interference when the beginning of one pulse overlaps with the end of another. This pulse dispersion is a function of both the data rate (pulse width) and the distance the pulse travels. Currently available fiber optic systems have data capacities in excess of 1.2 gigabits per second and unlimited length. However, video capacities are limited to 1000 MHz on about 80 channels and have a range limit of 40 kilometers (24 miles).

Fiber optic repeaters do not amplify the optical signal, but convert it into its original electrical form and then back into an optical signal. This regeneration is required because amplification alone would not correct pulse dispersion in the data mode. Video may not presently be amplified more than once due to degradation of quality. Video and data may not be transmitted on the same fiber as video is transmitted via analog modulation whereas data is via digital modulation.

The considerations in the design of a fiber optic cable communication network are much the same as in the design of a twisted pair or coaxial cable system. However, unique considerations include:

- **Failure Potential** - As a result of the many necessary regenerations of the communications signal, the potential for a catastrophic failure is great and should be considered in the design of the communication network by employing a “ring” configuration.
- **Splices/Connections** - Field splices/connections between fibers or fiber and any other communication medium must be much more precise and clean than with any other medium, and, thus, should be considered in the development of project specifications and future maintenance.
- **Costs** - Fiber optic communications require special transmitters, receivers, and electro-optic electronics, however, the cost of fiber optic is now relatively comparable with twisted pair.

In summary, fiber optic cable communication technology is rapidly evolving into a proven and reliable technology, adequate for data, voice and video transmissions.

2.3.2 Leased Lines

Leased circuits have the flexibility and speed to apply to the communications system as trunk connections. Typical available leased circuits include voice grade/data grade analog (1200 bps), digital (56 Kbps), T-carrier and SONET.

Leased telephone is a very reliable communications solution in that there is a grid redundancy element due to the general coverage of the carrier's network. One potential advantage over a dedicated network is that maintenance responsibilities are shifted to the telephone company. There are, however, a number of potential drawbacks with the leased approach, including:

- Freeway Access-The leasing agency is typically required to provide the telephone company with a conduit between the field cabinet and the nearest telephone facility. The required distance may be similar to the cost of conduit required for a dedicated network. However, these capital costs may be passed on to the client in the form of lease costs, versus a higher "up-front" cost as required with dedicated networks.
- Cost-The costs for a leased network do not end with the installation of the conduit. There is a monthly charge, and no guarantee that recurring charges will not significantly increase in the future. Several systems have converted from leased telephone to jurisdiction-owned communications because of previous rate increases and the uncertainty of future hikes. Contractual arrangements which fix rates at a specific level over a number of years are recommended.
- Video Transmission-As a result of the improvements in CODEC technology during the last year years, the transmission of video over leased telephone is not as significant of an issue as it once was. Nevertheless, use of leased facilities for video requires a dedicated T-1 circuit, a CODE unit with Channel Service Unit/Digital Service (CSU/DSU) at both ends of the circuit, and for many multi-channel CODEC designs, an environmental enclosure (with heat and air conditioning) to house the CODEC.

2.3.3 Twisted Pair Cable

Twisted pair cable has historically been the medium most frequently utilized for the communication network required in traffic signal systems. Twisted pair cable networks can be either agency owned or leased (phone lines), and can be installed either underground or overhead. Individually insulated copper wires are twisted into pairs which are combined into shielded cables consisting of 6, 12, 25, 50, 75, 100, 150, 200, 300, 400, or 600 pairs. Full duplex (i.e., two-way) "simultaneous" communications to one receiver require two-pairs or four-wires. This technology has a usable bandwidth of 300 to 3000 Hz with data transmission rates of 1200 bits per second. Higher data transmission rates can be achieved with conditioned (with loading coils) communication lines. Data transmission is accomplished with Frequency Shift Keying (FSK). No special maintenance (beyond that needed for traffic signal maintenance) is required.

Transmitters used in twisted pair cable communication networks can be "turned around" (i.e., switched on and off) very rapidly, allowing several receivers, or traffic signal controllers, to operate on one communication channel. Traffic signal control systems can be configured with between 4 and 16

controllers on each channel, depending on the amount of data to be transmitted during each communication. To allow more than one receiver on a communication line, Time Division Multiplexing (TDM) is employed.

The attenuation (signal loss) in a twisted pair communication network is directly related to frequency such that the degree of attenuation increases as the square of the frequency. Additionally, as the conductor size decreases (gauge increases), the signal loss increases. Signals in each channel of a twisted pair network must be amplified approximately every ten miles. Noise in a twisted pair cable communication system is primarily caused by 60 Hz sources, however, the modems used in the network and the cable shielding eliminate most of the noise.

Twisted pair cable is adequate for data and voice communications. Recent developments in video image compression allow slow-scan video pictures also to be transmitted.

Considerations for the design of a twisted pair cable communication network include:

- **Number of Pairs** - The number of pairs necessary in the network are a function of the quantity of field drops, the maximum number of drops permissible per channel (data bandwidth requirements and the transmission speed), and the network configuration. A **communication control unit** (CCU) is often required as a result of the significant quantity of drops.
- **Cable Routing** - Considerations related to the cable routing include the drop locations, opportunities presented by existing communication lines, cable termination requirements, and costs.
- **Cable Installation** - The design and installation of underground or overhead twisted pair cable must consider the cable diameter, stiffness and weight, maximum allowable pulling strength, and conduit size and bending radii, as appropriate.
- **Environmental Factors** - Consideration must be given to the noise and moisture potential of the installation.
- **Amplifier Requirements** - For traffic control applications, amplifiers (repeaters) are normally required for cable runs greater than ten (10) miles.

In summary, twisted pair cable communication technology is a proven and reliable technology, adequate for data and voice transmissions. Additionally, in recent years, various technologies have been developed to transmit video images over twisted pair cable. One such technology is the “slow scan technique”, which provides a video image using less frames per second than that of full motion video. Full motion video may also be transmitted over short distances-from communication hub to the traffic management center (less than 2000 feet). For longer distances, other communication media (coaxial cable, fiber optic) can be utilized for full-motion video transmission.

2.3.4 Spread Spectrum Radio

Spread spectrum is a wide band RF modulation radio technology developed during World War II for secure radio communications. The technology prevents jamming and interference and is resistant to multi-path reception. Until 1985, spread spectrum technology was restricted to military use.

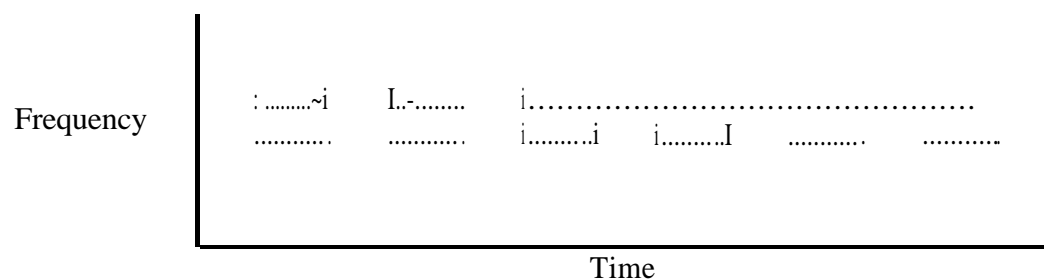
Spread spectrum technology is now being used as an alternative to hardwire data communications. The technology is increasingly being used for data, voice and video communications particularly in Local Area Network (LAN) applications. Spread spectrum provides high data rates at low transmit power. A recent FCC ruling (Part 15) determined that no license would be required for low power spread spectrum transmitters in the following bands:

- 902-928 MHz (26 MHz bandwidth)
- 2400-2483.5 MHz (83 MHz bandwidth)
- 5725-5850 MHz (125 MHz bandwidth)

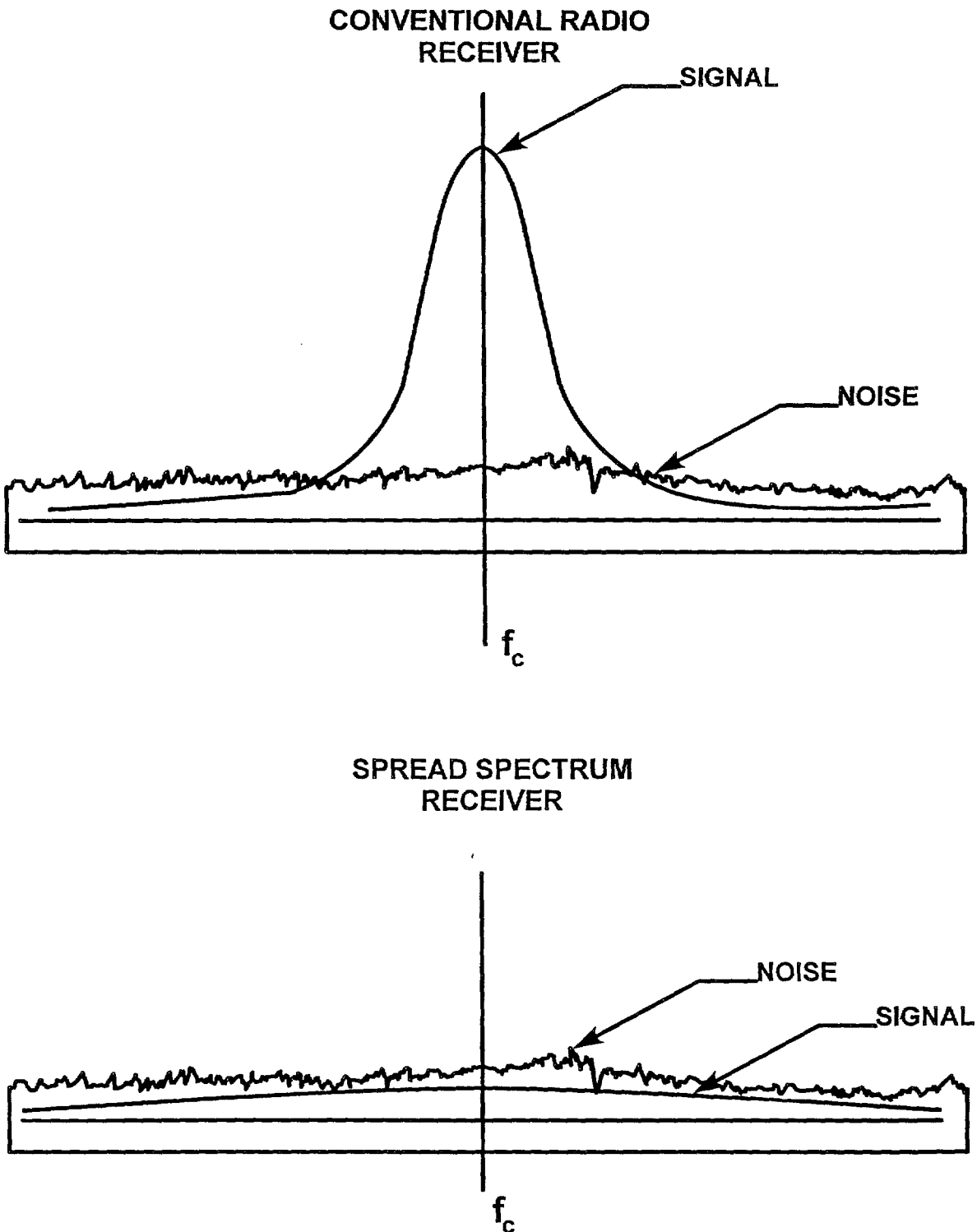
A spread spectrum transmitter spreads its signal over a bandwidth far wider than that used by conventional, or narrow band, modulation techniques. The receiver detects the desired signal, compresses the signal to the original frequency range and filters out interference. This technique is known as Code Division Multiplexing (CDM).

A spread spectrum receiver can successfully decode a spread spectrum signal even if the noise level exceeds the signal level. The bandwidth of a spread spectrum signal (which carries the same data rate as a conventional signal) exceeds by many times a conventional signal's bandwidth. Therefore, the spread spectrum transmitter can repeat the signal many times over or otherwise encode it, all within the spread spectrum signal bandwidth. This results in a "processing gain" which appears as a factor in the power budget. Since each network works with a different code, different networks in the same location can use the same band. Figure 2 illustrates the difference between a conventional radio and spread spectrum signal.

There are two techniques used in spread spectrum technology for distributing the data over the bandwidth, direct sequence and frequency hopping. Direct sequence technology means that the spread spectrum band is "spread" over a specific portion of the frequency band, as shown below:

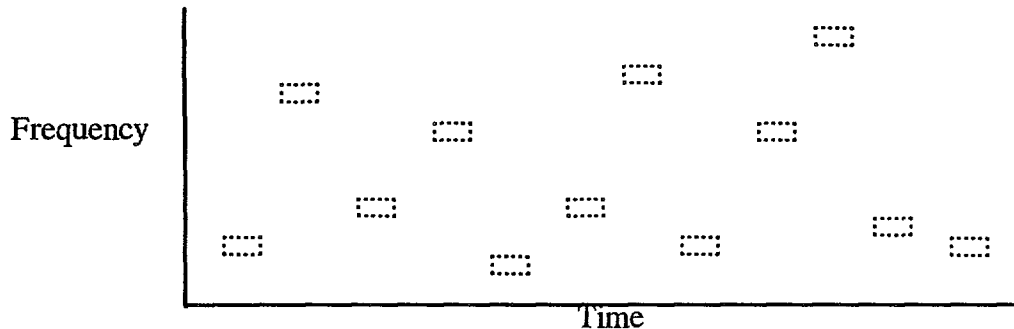


Most spread spectrum transmitters on the market have multiple channels for this type of transmission.



*Frequency Spectra of Conventional
Radio and Spread Spectrum Radio*

The second type of spread spectrum technology uses a frequency hopping radio technique. This means that the radio signal hops across frequencies in the band in pre-defined patterns. The signal is not at any one place in the band long enough to be hampered by the presence of an interfacing signal somewhere in the band. See example below.



Spread spectrum is inherently “noise resistant” since the power of the noise signal is decreased greatly when the receiver recreates the original narrow band signal. However, the interference generated by spread spectrum radio may prove unacceptable to some systems which use the same frequencies (e.g., broadcast TV), but may be imperceptible in other cases (e.g., FM radio, voice communications).

The most applications of spread spectrum radio to date have used the 902–928 MHz band. As indicated earlier, no facilities license is needed from the FCC for this band. Part 15, paragraph 15.227 of the FCC ruling contains spread spectrum radio’s current major constraints including, a maximum peak output power of 1 watt and a maximum effective radiated power of 4 watts. Spread spectrum radio signals travel through the atmosphere along a line-of-sight path. This technology has a usable bandwidth of 25 Kilohertz (KHz) per channel with transmission rates of up to 9600 bits per second for spread spectrum.

For traffic control system applications, the range of a spread spectrum radio installation ranges from about 0.5 miles to several miles and, depending on the application, may require repeaters. Commercial equipment currently supports data rates of approximately 200 Kbps, thus satisfying most data requirements for field equipment and “low end” coded video transmission.

In the microwave region of 900 MHz and above, line of sight to the receiving antennas is generally required. However, propagation relationships govern the actual clearance required of obstacles and adjacent structures. Use of a higher frequency band, such as the 2400–2483.5 MHz band, demands the use of a more restrictive line of sight due to the narrower fanning pattern present in higher frequencies.

The cost of implementing a spread spectrum system is typically in the \$3,500 range per field unit, which includes radio, Yagi or omni antenna and cabling (but not including traffic cabinet enclosures).

TABLE 4. CHARACTERISTICS OF WIRELESS TECHNOLOGIES

Technology	Characteristics
Spread Spectrum Radio	<ul style="list-style-type: none"> • Does not require FCC license in 902-928 MHz band • Can transit data and <u>compressed video</u> • Easy and flexible installation and maintenance • Line-of-sight is available for this application • Uses low transmitter power • Can be used in a mixed system of wire and other wireless interconnections • Relatively low equipment cost • Potential for other City applications such as telemetry • Currently in use for traffic applications in other cities • Compatible with Type 170 controllers and has been tested with QuicNet system • Relatively small unit and antenna for installation on signal mast arms • Redundancy could be easily provided by adding "hot stand-by" units • Requires training and more sophisticated equipment and specialized technicians than hardwire interconnection • Not suitable for full motion video transmission • Relatively new technology for traffic compared with hardwire interconnect • Requires external antenna/cable compared to radio
31 GHz Microwave	<ul style="list-style-type: none"> • Local frequency coordination is not required by FCC. Only federal application is needed. • Could be used for full motion video transmission (Model 3123 GDI) • Compatible with Type 170 controllers • Relatively easy to install • Can be used in a mixed system of wire and other wireless interconnections • Currently in use for traffic application (Model 3100 GDI) • Suitable for point-to-point application • Complete direct line-of-sight is required for proposed operation • Maximum range is 1.5 to 2.0 miles without repeater • Has shown degradation of signal strength during rain storm (City of Long Beach, Las Vegas) • One unit composed of transmitter and receiver/antenna on mast arm. Not easy to maintain, requires bucket truck. • Relatively higher cost than spread spectrum radio • Requires training and more sophisticated equipment and specialized technicians
450 MHz Radio	<ul style="list-style-type: none"> • Only base station is required to be licensed by FCC • Can provide voice communications to maintenance staff • Can propagate into built-up areas and buildings (no direct line-of-sight is required) • Low cost compared to spread spectrum radio and microwave • Could be used in combination with other technologies • Limited channel availability in urban areas (traffic control and telemetry are secondary to mobile voice used for public services, fire and police which are primary) • Has shown higher error rate in its traffic application (5% in City of Lancaster) • Frequency search is required

2.3.5 Microwave

Microwave signals are radiated from an antenna and propagate through the atmosphere along a line-of-sight path. The frequencies used must be unique in that area to prevent interference from other microwave transmissions. Because of this constraint, microwave frequencies are licensed by the FCC; and it can be very difficult to obtain a microwave frequency allocation in crowded urban areas. When frequencies are available, they are usually in the higher frequency bands (18 and 23 GHz), which have reduced transmission distances.

Weather conditions and local topography determine the feasibility of microwave transmission as a communications medium. The effect of rain, fog or snow can attenuate/reduce the radiated power of the microwave signal.

Typical configurations for microwave communications can be point-to-point or point-to-multipoint, depending on the requirements of the network. The point-to-point network is one where the transmitter propagates the microwave signal to a receiver located at some distance (0.5 miles to 40 miles, depending on the frequency utilized). The point-to-multipoint system requires one transmitter propagating the microwave signal to multiple sites of receivers located in the field.

The utilization of microwave communications falls into two major categories. The first is an analog microwave system in which the method of modulation is typically FM (frequency modulation). This type of system is utilized for the transmission of video images (CCTV) which provides a full motion image. The second is a digital microwave system in which the method of modulation is typically TDM/TDMA (time division multiplexing/time division multiple access). This is an all digital system which is used for data and voice. The transmission of video can be accomplished but requires digital video compression techniques.

2.3.6 Satellite

Satellite is similar to microwave in that both use some of the same frequencies for transmission through the atmosphere. With satellite, however, instead of utilizing a line-of-sight transmission path, the signal is directed at a satellite transponder.

Satellite service has been available for many years for voice, data, and video transmissions. Very Small Aperture Terminal (VSAT) satellite systems use 12 GHz. The satellites themselves have a geosynchronous orbit above the Earth's equator, thereby appearing stationary in the sky and providing 24-hour a day coverage. These high-altitude satellites also avoid various earth-level interferences.

In addition to the satellite links, a central hub element and earth stations are also required to provide a VSAT-based communications network. The "Hub" may be located at a traffic management center, and serves as the focal point for communications between the remote sites and the control center.

The "earth station" is the communications component of a remote site. The earth station consists of an antenna, an RF transceiver mounted on the antenna, and a digital interface unit. For video applications, the digital interface unit is connected to the camera's central receiver (for pan, tilt, and zoom) and a CODEC unit.

In general, the VSAT medium is ideal for long-distance communication links (e.g., communications between the Caltrans District 12 TOC and Sacramento) since the costs of leasing VSAT channels are independent of distance. In general, VSAT becomes cost-effective relative to leased lines at a transmission distance somewhere in the range of about 300 miles.

Since VSAT lease costs are a function of the percent of time that the inroute/outroute link is actually utilized, this technology may also have cost-effective applications in a localized communications network where transmissions are required only on an as-needed basis, such as for CCTV that is only used as needed for incident verification.

Another potential use of VSAT is for communications where a dedicated cable network and/or leased telephone circuits are not readily available, or where a surveillance camera needs to be mobile—for example, in conjunction with the maintenance and protection of traffic during roadway construction, and during major incidents in areas where CCTV is not available, but real-time video surveillance would be a great asset.

2.3.7 Cellular Radio

Cellular radio is a technique for frequency re-use in a large radio communications system. It is mainly known by, what is its largest implementation by far, the mobile telephone network. Cellular radio is based on the concept of “cells” which are 2 to 20 miles across, the center of each is a control radio which handles the network management functions including the assignment of frequency sub channels. A radio requests a frequency over a control channel and one is assigned by the cellular control system. The cellular layout allows frequencies to be re-used in non-adjacent cells.

Due to the demand for car telephones, there is new, second generation of systems emerging which will be characterized by digital speed transmission and enhanced network control. The new system will provide greater bandwidth and frequency re-use capability. There is current development using this technique for data systems. However, new networks will likely have the same or similar rate structure making them unsuitable for constant (high-use) connections with fixed (as opposed to mobile) devices such as field hardware. On the other hand, the new cellular alternatives do appear to have potential for driver information transmissions such as in-vehicle navigation devices.

3. TRAVELER INTERFACE

A multitude of technologies are available for transmitting information and advisories to the traveler. The ITS architecture should be able to support the technologies through one consistent interface and data resource, so as to achieve consistency and the capability to monitor the information that is disseminated. The quality of the data that is disseminated will be integral to the success of ITS.

There are two primary categories of information to be disseminated: Pre-Trip and En-Route. The character of this information differs with the intended “audience”. For example, providing en-route information to transit users requires a different type of information than that for private vehicles with in-vehicle navigation system.

To disseminate the information, a variety of audio and visual techniques are considered as candidate elements of the architecture. These are described in general terms in Table 5. For both audio and visual information techniques, information techniques that are external to the infrastructure (i.e., vehicle-based or autonomous) are available as well as techniques which include components physically present along the roadway network (roadway-based).

The potential dissemination techniques required to reach the traveler for pre-trip and en-route information is described in Table 6 in terms of both traffic and transit information.

3.1 Interface Between Surveillance, Processing, and Traveler Interface

The accuracy and timeliness of the information disseminated to the public is largely dependent on the accuracy and quality of the information received from the field. As is evident from the Surveillance section, this information may be received from a variety of sources and can cover an extensive number of parameters. However, in order to provide the desired information to the traveler, necessary actions and response techniques must be taken by the system. Also a reasonably detailed level of information must be coordinated to provide a single pool of information. This “Traveler Information Database” (TID) may consist of the following layers of data:

- **Roadway Traffic Data.** This would consist of appropriate raw traffic data indicated by location and direction, including measured volumes, speeds and occupancies. Additionally, calculated Measures of Effectiveness (MOE’s) could be included for defined sections of the ITS Network. Such information may include estimated delays along a section of roadway as well as estimated travel times between specific points along the network.
- **Transit Data.** This would include, at the minimum, schedule data for transit routes. Given location information from AVL, it should be possible to estimate times of arrival and travel times of transit for use in comparison with using private vehicles.
- **Incident Data/System Actions.** This would be a running log of system incidents as confirmed by Systems Operators (from one or more agencies). In response to these incidents, agencies may approve a number of actions. Such actions may include CMS and HAR messages, as well as route diversion strategies or actions to close an additional lane for incident clearance. These agency actions would be tracked by the TID and logged.

The TID serves as a basis for taking the collected data and system responses as well as distributing the correct information to the appropriate services for the various users and interfaces. It should be possible to monitor and edit the information contained in the TID. The Operator will then be able to edit the information at one location rather than individually for each information subsystem. Thus, for example, Operators would not have to correct information being sent to the media and also to in-vehicle devices.

TABLE 5

SUMMARY OF TRAVELER INFORMATION TECHNIQUES
Visual or Audio

	Type of Technique	Visual	Audio
Infrastructure	Roadway-based	Changeable Message Signs (CMS)	Highway Advisory Radio (HAR)
	Non-roadway-based	Graphics Displays - Cable TV Broadcast Display of CCTV Images Teletext Silent Radio Videotext/Bulletin Board Systems	Highway Advisory Radio (HAR) Page Technology Radio Broadcast (from Media Interface) Digital Radio Receiver or Radio Data System
Vehicle	Private or Commercial Vehicle	In-Vehicle Displays - Graphics - Text - Advisory Messages	Digital Radio Receiver or Radio Data System
	Transit Vehicle	In-Vehicle Displays (Messages Graphics)	Information from Driver or Digitized Voice

TABLE 6

TECHNIQUES TO SATISFY SPECIFIC INFORMATION NEEDS

	Driver Location	Roadway-Based	Non-Roadway Based
Private Vehicle	Pre-Trip		Highway Advisory Telephone (HAT) Pager Technology Radio Broadcast (from Media Interface) Broadcast Display of CCTV Images Silent Radio Videotext/Bulletin Board Systems Teletext Graphical Displays - Cable TV
	Start of Trip (Before congested roadway)	Changeable Message Signs (CMS) - Trailblazer - Surface Street Full-Matrix Highway Advisory Radio (HAR)	In-Vehicle Displays (ADIS) Radio Data Systems/Pager Technology Radio Broadcast (from Media Interface) Digital Radio Receiver (ADIS)
	On congested roadway, upstream of incident	Changeable Message Signs (CMS) - Freeway Full-Matrix Highway Advisory Radio (HAR)	In-Vehicle Displays (ADIS) Pager Technology Radio Broadcast (from Media Interface) Digital Radio Receiver or Radio Data System
	On diversion route	Changeable Message Signs (CMS) - Trailblazers - Surface Street Full-Matrix Highway Advisory Radio (HAR)	In-Vehicle Displays (ADIS) Pager Technology Radio Broadcast (from Media Interface) Digital Radio Receiver or Radio Data Systems/
Vehicle	At transfer points		Kiosks (Interactive Graphics)
	En route		In-Vehicle Displays (Messages, Graphics)

The continuing evolution and adaptation of advanced technologies is resulting in a significant number of new applications for dissemination. Such advances have come in communication, display, and processing technologies, with the overall direction heading toward providing real-time traffic information, both as a component of the highway infrastructure (the Smart Highway, Street and/or Corridor) and as a component of the vehicle (Smart Car). As the level of information improved, such inputs will be critical to the development of Automated Control Systems (AVCS), which will need to rely very heavily on real-time information and operations strategies in order to be functional and useful. As a goal of the federal IVHS Act of 1991 (a part of the ISTEA transportation program), such systems are to be implemented on a test basis by 1997.

3.2 Media Communications

There are be at least three levels of media interface with the ITS architecture. Each level provides a unique type of information such that they are complementary to one another.

Text-Based Information

This information can be transmitted in the form of traffic status summaries, which could summarize traffic information for each freeway, including incidents, delays, travel times, and suggested alternate routes or transportation modes (i.e., transit). Text-based information can be transmitted via either dedicated or dial-up leased line. Information may be sent either on a non-interactive basis (e.g., teletype) or on an interactive basis, based on the selection of the desired information by the user from a menu. Frequency of update/refresh rate is dependent on how the information is retrieved and updated.

Graphical Information

Graphical displays of traffic status provide an attractive and informative way of presenting information to the media as well as to the general public. Based on field traffic data and pre-set data thresholds, appropriate color-coding for parameters such as speed, occupancy, and volume can be utilized to represent traffic flow conditions for each data station along a freeway.

Many of the Traffic Operations Centers (TOC's) use these types of displays. It allows the operator to zoom in on particular portions of the network, or be able to view the entire network at once.

Graphical information may be sent from the ITS network to the media via dedicated leased lines. However, software needs for the media users are greater than for text-based transmission, unless the data is sent in a non-interactive format such as the National Television Standards Committee (NTSC) RS-170 format.

Interactive graphics for media users involve the use of a graphics software and geographic database configuration that is identical or compatible with that of the ITS architecture. The media user's PC equipment should have appropriate graphics enhancements for information reception. A typical set of enhancements includes use of a large screen with a special graphics driver card allowing high resolution. If selected media are permitted to transmit the interactive graphical data to the public, the media would be responsible for conversion of the RGB data to NTSC format for broadcast or cable TV transmission.

Non-interactive graphics transmission consists of broadcast images that could be sent either on separate channels for different TOS network areas (so the media or viewers could monitor one area continuously) or the images could be rotated in a “slide show” format and be transmitted on a single channel. This is analogous to “teletype” text transmission discussed above where the user receives information but cannot query the type or frequency of information to be sent.

Video Information

If a video intertie with media is deemed appropriate, CCTV images (NTSC format) could be sent for those locations where incidents are present or for selected freeway locations. The amount of flexibility and number of images available to the media would depend on the resources available to multiplex the data for transmission to the media and what level of manipulation (switching, number of monitors, etc.) the media outlet(s) would have available.

3.3 Changeable Message Signs

Many recent advancements have been made in motorist display systems. The information provided by a CMS ranges from the most basic level (a fixed blank-out message indicating a specific recurring or non-recurring condition) to a medium level (dynamic route guidance using an adaptation of conventional route trailblazers or directional signing) to the highest level (dynamic, real-time congestion, incident, and best route information using full-matrix signs). Table 7 shows potential applications for these different levels of signs.

The emphasis of freeways has been on providing the highest-level of information; in other words, full-matrix CMS. However, use of other types of CMS, particularly along surface streets parallel to freeways, is a high priority. The Smart Corridor integration with local roadway operations is considered necessary to improve traffic flow through those corridors. An overall strategy for the use of dynamic route signing (trailblazers) for indicating alternate routes is thus appropriate. Figures 3 through 5 illustrate sample “regular” and “portable” changeable message sign installations.

Additionally, the use of low-power HAR can be indicated to the public through the use of blank-out signs. These are particularly useful for surface street traffic approaching freeways.

Typical Applications

Changeable message signs (CMS) can provide dynamic information to motorists regarding a variety of conditions, including:

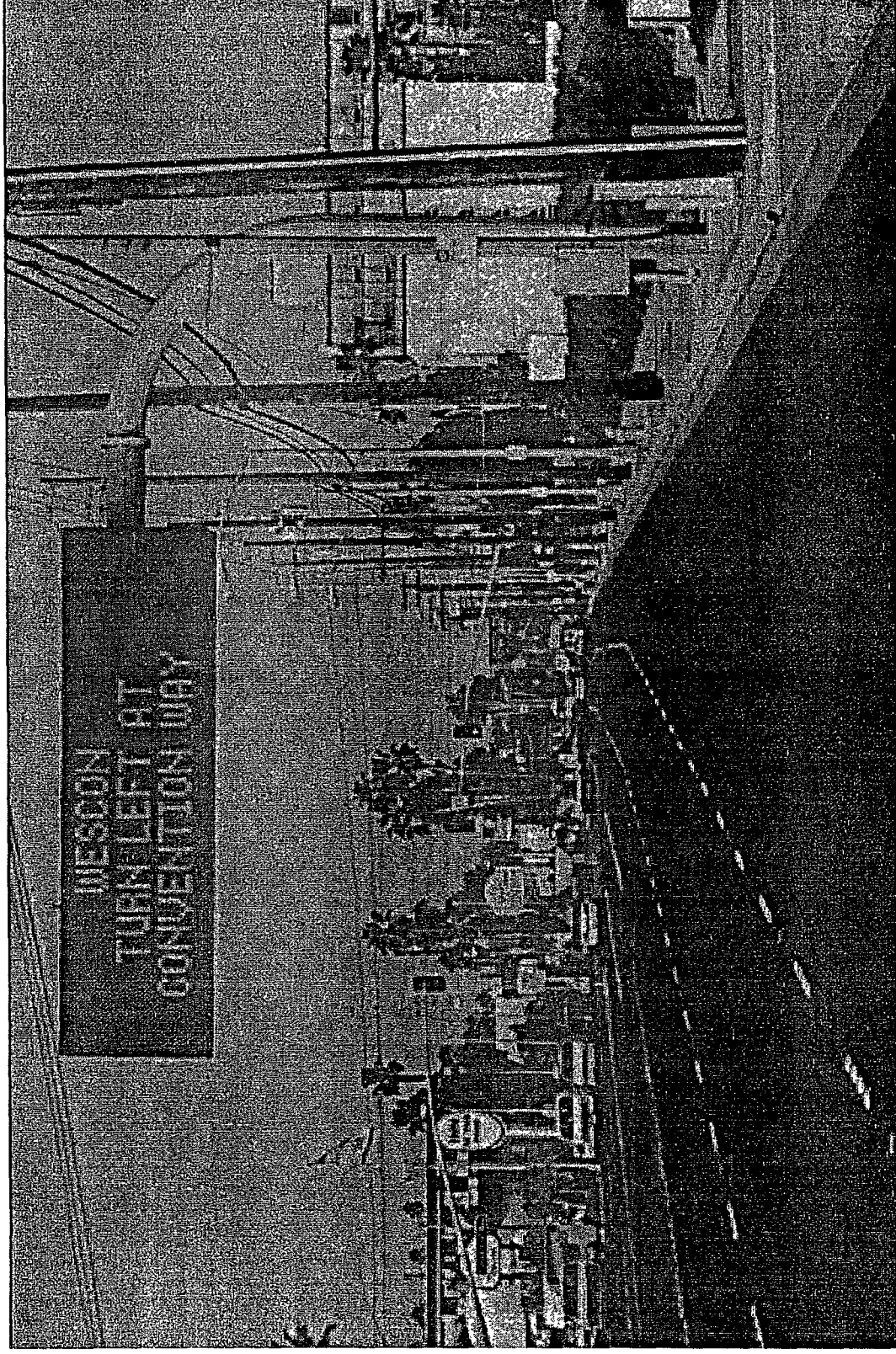
- **Congestion**-Changeable message signs can be used to warn motorists of congestion that lies ahead as a result of an incident, bottleneck, or special event. In addition, the CMS can be used to provide warnings when unexpected queuing occurs in areas of restricted sight distance such as around a curve or over a vehicle crest.

TABLE 7

TYPICAL APPLICATIONS OF CHANGEABLE MESSAGE SIGNS

Message Type	Sign Type		
	Full Matrix (Lines 1, 2 or 3 or Alternating Display)	Trailblazer	Blank-Out Sign
<i>Problem Statement:</i> Delays or Congestion Ahead... On Connecting Route...	Line 1 Line 1 Line 1	Not Used	Not Used
	Line 1 Line 1 Line 1 or 2	Not Used	Not Used
<i>Status:</i> Lanes Closed HAR in Operations	Line 2 or 3 Not used for this purpose	Not Used Possible depending on sign layout	Not Used On when HAR activated
<i>Route Guidance:</i> Alternate Route	Line 3, Alt Display	Yes	Not Used

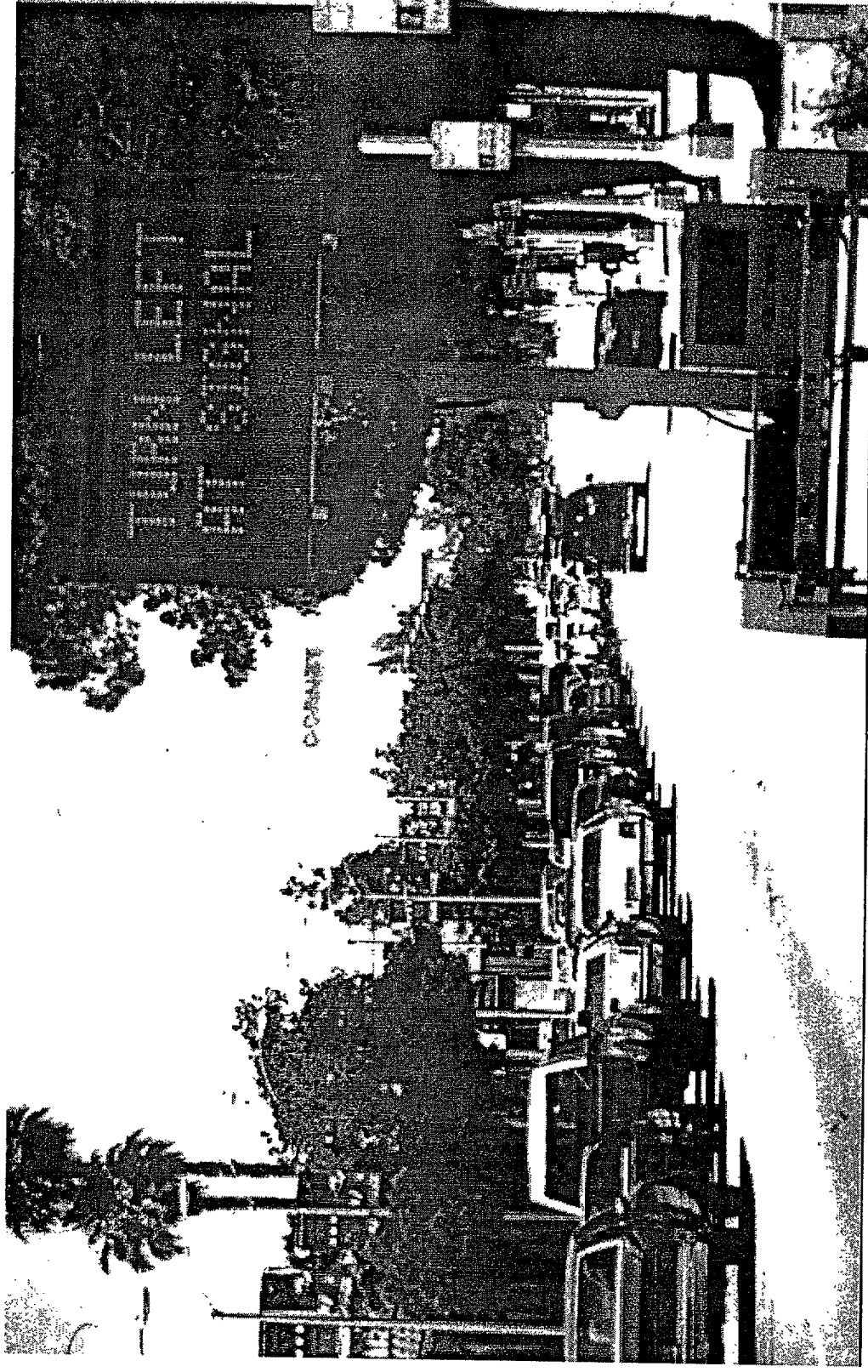
Omaha Metropolitan Area ITS EDP Study



Changeable Message Sign

Figure 3

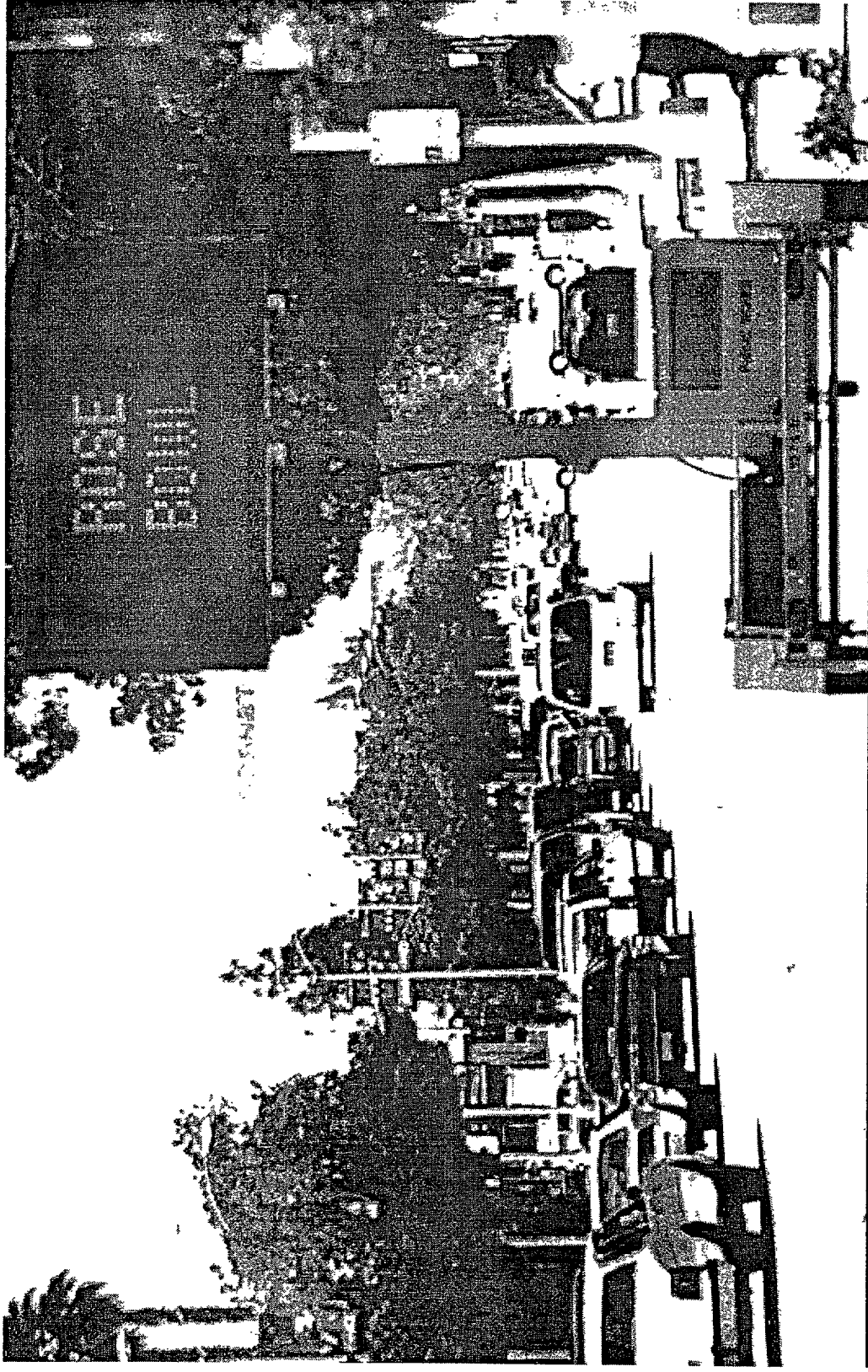
Omaha Metropolitan Area ITS EDP Study



Portable CMS Sign

Figure 4

Omaha Metropolitan Area ITS EDP Study



Portable CMS Sign

Figure 5

- **Navigation**-Changeable message signs can inform motorists of alternative routes that are available, or that must be taken.
- **General Guidance Information**-Directions, plus ways to obtain additional information through other means (e.g., radio).
- **Maintenance and Construction Work Sites**-Changeable message signs can be used to warn motorists of lane closures in progress so that they can avoid abrupt lane changes. End of queue warnings and alternative route information can also be provided to motorists approaching work sites.

Sign Displays

Several different types of changeable message signs have been developed. One is the “blank-out” sign in which a single message can be turned on or off as conditions require. Signs of this type might be applicable to Highway Advisory Radio sites being turned on in advance of a particular segment whenever radio messages are being broadcast. If only a few messages are needed at a particular site, then a rotating drum sign-consisting of a three or six-sided prism for each line of the message-may be applicable. The most flexible type of CMS is the matrix sign, which uses individual pixels (on/off) combined to portray a desired legend. Matrix operations include:

- **Character Matrix**-An individual module for each character (letter). The letter spacing and maximum letter width is fixed.
- **Line Matrix**-A single matrix for each line. This allows proportional spacing between letters, but limited graphics capability.
- **Full Matrix**-No built-in divisions between letters or lines. This configuration allows the greatest flexibility in the size and stroke of letters, plus graphics symbols.

Another advantage of full-matrix CMS is the ability to display graphics, thereby further enhancing message readability. Graphics should be kept simple, be easily recognized, and be familiar to motorists. The most useful graphics are those which do not require an accompanying explanation on the sign, such as directional arrows, interstate shield, airplane, and lane reduction (based on the international diamond sign).

Several CMS display technologies are available as described below. The following technologies are summarized in Table 8 based on a comparison of visibility, power and maintenance requirements:

- Flip Disk
- Bulb Matrix (Incandescent)
- Fiber Optics
- Light-Emitting Diode (LED)
- Hybrid (Flip/LED, Flip/Fiber)

TABLE 8
EVALUATION OF CMS DISPLAY TECHNOLOGY

Criteria	Sign Type				
	Flip-Disk	Bulb-Matrix	Fiber Optic	Led Cluster	Hybrid
Visibility Day	Good	Excellent	Excellent	Good	Good-Excellent
Visibility Night	Fair	Excellent	Excellent	Excellent	Excellent
Power Requirements	Very Low	High	Low	Very Low	Low
Maintenance Required	High	Very High	Low	High	High

Message visibility and legibility under all lighting and weather conditions is the most important attribute of a changeable message sign. The chance that a driver will be confused by a display, or miss a sign altogether, must be minimized. Purely reflecting signs do not provide the necessary quality or visual conspicuity (i.e., “punch”). Accordingly, light-emitting CMS technology-bulb, LED, fiber, hybrid-are being installed in most transportation systems.

As to which of the light-emitting technologies is “best”, recent CMS evaluation studies provide somewhat contradictory conclusions. All are very similar in performance with respect to target values and mean legibility distance under various lighting conditions. However, only bulb-matrix has been in operation for a sufficient period of time such that its reliability and life-cycle costs can be determined. However, the newer (LED, fiber, hybrid) technologies offer the opportunity for longer life and reduced maintenance costs, due to the reduced power consumption requirements and longer design life of the light-emitting elements.

Sign Controller and Firmware/Central Software

CMS manufacturers can provide a complete and fully operational sign system. But the sign controllers, local firmware, central software, and communications interface are generally proprietary. This means that if the agency wishes to expand the sign system, they will essentially be “locked” into the original manufacturer. To avoid this predicament, some systems are specifying their own sign formats and communications protocol during the design phase. It becomes the sign manufacturer’s responsibility to provide a sign and sign controllers conforming to these specifications, thereby eliminating any proprietary hardware or software which might tie agency to a specific vendor during future system expansions.

Sign Usage and Operation

The purpose behind changeable message signs is to provide dynamic information regarding existing traffic conditions such that motorists can make intelligent route choices. CMS should not merely be used to convey information that could also be displayed by static signing. Rather, these signs should provide timely and accurate information which reflects the current conditions, and which can be used by the motorists to improve their trip time. Moreover, CMS should not provide trivial information-telling drivers something they already know. Sign messages themselves should be composed with words that are

used in everyday conversation by the motoring public in the geographical location of the system. As an example, some of the wording issue addressed by the INFORM system on Long Island include:

- Use of the words “Delays” rather than “Congestion”.
- Descriptions like “CAR FIRE” are not used in that this may make the incident interesting, and motorists might choose to see it instead of diverting.
- Alternating messages are not used.
- Use of Exit numbers instead of mileage to identify geographic location and extent of delays.
- Displaying ‘NORMAL TRAFFIC AHEAD’ when no delays exist between the sign and the next downstream sign.

Other systems utilize other forms of “non-event” messages. For example, the system in Toronto displays guidance information (e.g., identifying a particular route for the airport) as their non-event messages. The State of Maryland displays public service safety messages (e.g., USE SEAT BELTS/SIGNAL WHEN CHANGING LANES). The Illinois Tollway do a combination of public safety and day/time messages, as well as construction updates.

3.4 Highway Advisory Radio (HAR)

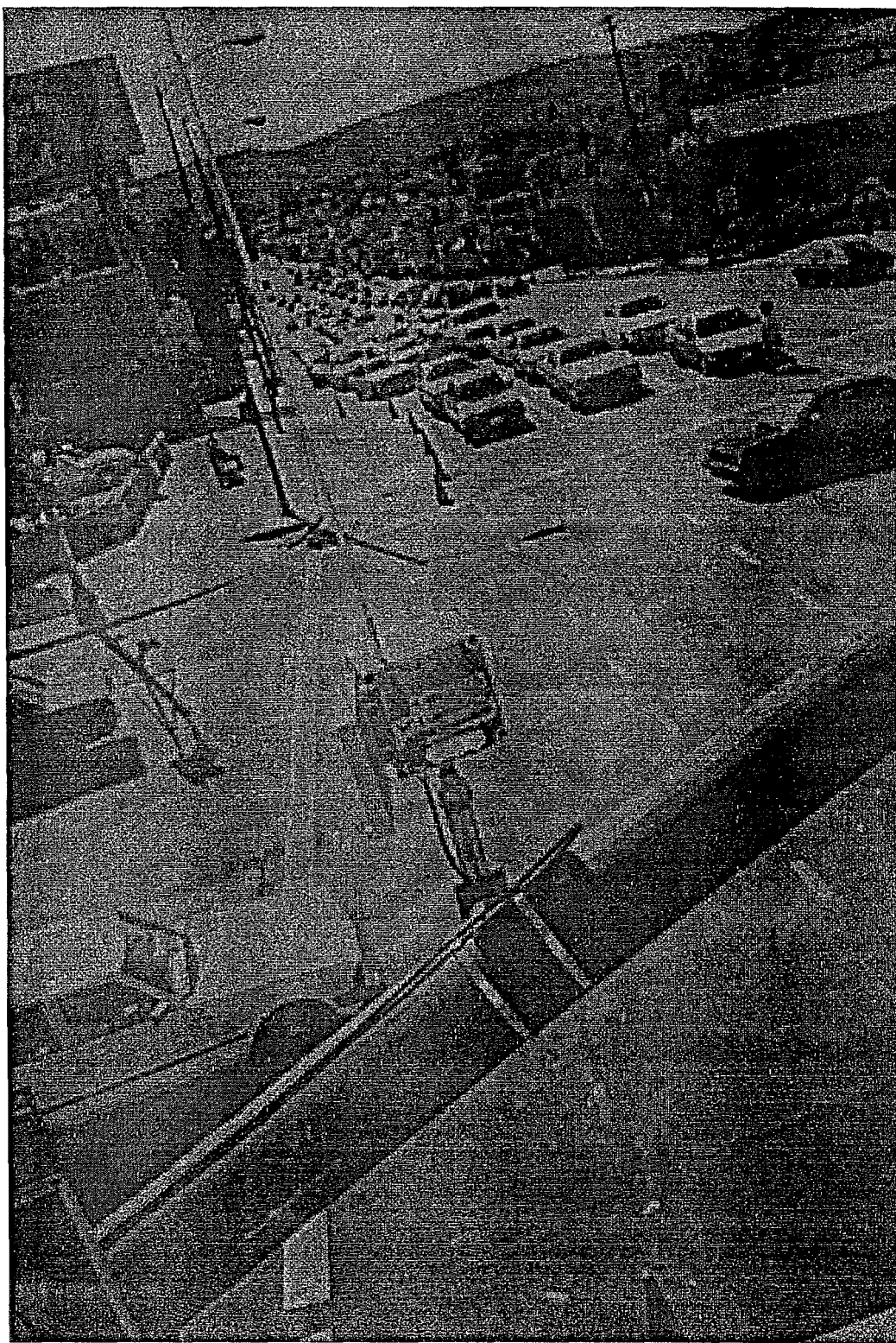
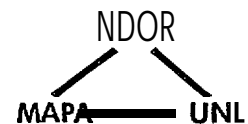
The HAR is intended to provide more specific traffic information as key locations on an more immediate basis than is possible through traditional commercially broadcast traffic reports. HAR can utilize either live messages, pre-selected taped messages, or synthesized messages based on information from the Traveler Information System (TID). It is expected that area HAR systems would ultimately employ an automated Voice Response System (VRS), a microcomputer-based system which uses TID information as its basis for operation. The VRS then develops digitized audio messages for dissemination. Figures 6 and 7 illustrate sample HAR radio and sign installations.

Essentially, Highway Advisory Radio can rely upon either of two technologies for transmission as described below:

10-Watt Transmission (FCC Licensed)

When properly maintained and installed, 10-watt transmitters have a broadcast radius of approximately 3 miles. Based on the new FCC rules, broadcast on any frequency between 530 KHz and 1710 KHz can be used. However, the FCC rulings have opened up the former dedicated traveler information/HAR frequencies (530 KHz and 1610 KHz) to commercial broadcasting. Therefore, the potential for interference from commercial broadcasters has increased. The 10-watt HAR transmission is omnidirectional. Consequently, several adjoining 10-watt transmission zones may result in interference problems due to radio frequency interference of adjacent transmitters.

Omaha Metropolitan Area ITS EDP Study



Highway Advisory Radio

Figure 6



HAR Info Sign

Figure 7

Low-Power Transmission

This relatively new technology uses 0.1 watt transmitters (not requiring FCC licensing) interconnected and synchronized to form a zone. The zonal configuration allows relatively linear broadcast zones with 1800-foot spacings between the transmitters. Based on the most recent test results, low-power zonal transmission offers less interference and a stronger signal when compared with a more powerful conventional lo-watt transmitter. Configuration of several zones allows different messages to be broadcast in each zone. Also transmitters can be adjusted to that there is no overlap between zones.

Other Technologies

In addition to the above, a number of other technologies are available with the capability for broadcast on conventional car radios. One alternative is to have an institutional arrangement with one or more public radio stations similar to an arrangement maintained by the Minnesota Department of Transportation. In this arrangement, a station's regular programming may be preempted for traffic information. One drawback is that it will be broadcast region-wide while the information may only involve one or two locations.

A second alternative is the use of "leaky co-ax", a technology where direct buried coaxial cable provides linear coverage. However, this technology has not been widely utilized and direct burial cable poses a number of maintenance problems, particularly involving construction projects in the vicinity of the cable.

Finally, digital voice broadcasts can be accomplished using FM Side Carrier Allocation (SCA), which utilize the "sideband", or space between radio station frequencies. Specially equipped radios can tune in the sideband and receive the clear digital signal.

Operational Application

For applications in the Omaha area, the use of specific HAR messages for targeted groups of motorists augments the use of the CMS in that the HAR can provide more detail than can be provided on the CMS. However, as with the CMS, it is essential that the messages be timely and relevant. Both elements should be consistent with one another. Ultimately, a significant advantage of TID would be the use of the common database for automated message generation with all traveler information system components. Voice Response Systems, allowing automated voice synthesis from a computerized database, are in use today in Chicago, Illinois, where travel time and congestion information are generated from the regular five-minute system, there, congestion and travel time updates are also generated to the media.

3.5 Highway Advisory Telephone (HAT)

Highway Advisory Telephone (HAT) can provide the public with access to up-to-the-minute traffic conditions compiled in the TID. The traffic conditions, in the form of voice messages, are readily available through any public, private, business, or portable touch-tone phone. No further equipment should be required of the public to use HAT.

As with HAR, there are a number of voice response strategies available. However, unlike HAR, HAT cannot efficiently maintain live operators. Two other technologies, including tape loops (regularly

updated) and synthesized or digitized voice response systems, are technically feasible. However, with the implementation of digital signal processing and the decrease in computer processing costs, telephone information systems can be developed which use digitized speech. These new systems, called Voice Response Systems (VRS), can handle many simultaneous calls, and provide a real-time interface to the host database. In the TOS application, the TID would provide HAT (as well as HAR and other information elements) with the necessary information on which messages can be developed. This capability to handle data, as well as the ability to monitor and log operations, makes VRS an efficient tool for HAT.

3.6 Radio Data Systems

This technology involves use of digital transmissions along FM side channels to specially equipped audio and/or text receivers. The ITS architecture would, in all likelihood, provide a much more detailed database than currently available for these types of devices, and could encourage increased use of digital receivers. In addition to providing information for hand-held units, digitized information encoded through the proposed TID could also be received by vehicles equipped with special digital radio receivers with text displays. The digital codes would be converted to a digitized voice message and/or a text message to be displayed to the driver.

A key to making this technology viable for in-vehicle use is sending messages which are targeted to specific groups of motorists. These might include commercial vehicle operators (e.g., truckers, inter-city buses), as well as private vehicle operators. As the use of this technology by the public is dependent upon making it available, it is proposed that a capability to provide digital encoded data be made available through the ITS architecture, with the private sector continuing their work in developing receivers to convert the coded data.

3.7 Other Digital Interface Opportunities

3.7.1 Teletext

Transmission of congestion, incident, and advisory information is possible through use of a portion of a commercial television channel's bandwidth called the Vertical Blanking Interval (VBI). The ITS architecture can service the increasing teletext audience by providing an output to the World System Teletext (WST) interface through the TID. Depending on geographic locations, messages could be targeted to provide information relevant to specific geographic areas.

3.7.2 Silent Radio

Silent Radio could be accessed through some level of media intertie. As Silent Radio networks basically serve as a clearinghouse of information (much like commercial radio), the intertie would be relatively simple. Text-based information would be the prime candidate for transmission to Silent Radio networks.

3.7.3 Videotext

Videotext essentially provides a dial-up access for personal computer users. It is recommended that within the TID, a separate output be provided for access from computer dial-up users.

There are two possibilities for dial-up access of traffic information. Currently, most dial-up “Bulletin Boards” (i.e., Prodigy, on-line service) are character-based, and the use of Graphical User Interface for PC-based bulletin boards is in its infancy. Therefore, it may be appropriate to provide both a simple character-based output (text-based information, with possible simple character-based graphics to indicate congested areas or incident locations), as well as an interactive Windows or Macintosh-based access for GUI communications. The GUI interface would provide the capability of transmitting bit-mapped graphics as well as allowing multiple windows to show different levels of information.

One way to enhance the usefulness of videotext would be to develop a home software package which, through its communications interface, would allow the user to access the ITS data (including incident and route information) for trip planning and, after the user inputs the origin and destination, the software package could select the best route for the motorist.

4. NAVIGATION/GUIDANCE

This functional area addresses in-vehicle system and devices which assist the driver with route planning and route following. While the navigation/guidance function does not necessarily include information on real-time conditions, the more advanced systems typically provide this feature. Three types of components are associated with navigation and guidance:

- Location tracking
- Display Devices and Operational Software to Correct Digital Data to On-Screen Information and Permit User Interface and Processing of Data
- Infrastructure-to-Vehicle Communications and Data Transmission

The respective approaches and technologies are discussed below.

4.1 Location

In order to provide information that is pertinent to the individual driver, it is necessary to know his/her exact location. Methods used to determine vehicle location are described below. It is noted that these methods also apply to AVL.

4.1.1 Dead Reckoning

Dead reckoning is based on integrating measurements of direction and distance travelled to determine a vehicle’s location relative to an initial position. The measurements are made by distance (e.g., speed sensors) and heading sensors (e.g., magnetic compass) on the vehicle. Generally, dead reckoning methods also include correction/updating via map matching or one of the methods described below. Map matching corrects a vehicle’s position display by comparing the calculated position with a detailed map of the area. Correction typically occurs when the vehicle turns—for example, a vehicle can only turn at intersections with other roadways or driveways, so the actual position must come at such a location as identified on the maps.

4.1.2 Signpost

Signposts-consisting of a radio transmitter installed on the side of the roadway, or a loop detector/ferrite loop stick antenna embedded in the radio-broadcast a location code which is received in the vehicle. The location code and a vehicle identification code are then transmitted to the control center via a vehicle transmitter. Accuracy is dependent on the spacing and frequency of signposts, coupled with dead reckoning/map matching between signposts.

4.1.3 Radio Multi-Lateration

Radio multi-lateration employs a radio transmitter in the vehicle and multiple receivers in fixed locations. Measured parameters, such as the differences in signal arrival times or the horizontal directions of signal arrivals, are used to construct triangles based on time differences or signal arrival angles and the known location of the receiving sites to estimate vehicle location.

4.1.4 Loran C

Loran C uses a hyperbolic trilateration system in which several master and slave radio stations transmit signals a fixed time difference apart. This generates a series of intersecting hyperbolic curves, whose intersections determine the geographic location. Loran C accuracy is 300 to 700 feet, although the transmission speed (at 100 KHz frequency) can be affected by weather, thereby affecting accuracy.

4.1.5 Global Positioning Satellite (GPS)

GPS receives microwave radio signals from several satellites, from which it calculates the location based on radio triangulation. Accuracy for civilian-use of GPS is approximately 100 feet, although the high-frequency microwave signals may be blocked by tall buildings and tunnels, resulting in less accuracy.

4.2 Display

Information provided to the driver can include current vehicle position, real-time traffic flow conditions (e.g., areas of congestion, speed limits, travel times) on the driver's route as well as on alternate routes, guidance and route following directions, locations of traveller services (e.g., parking, eating establishments, etc.), or some combination. This in-vehicle information can be communicated in several ways, including:

- Map Display-the various items of traveler information may be overlaid on a map display of the region, including the roadway network.
- Text information and messages.
- Directional arrows indicating the next action (e.g., turn, change lanes, continue, etc.) that the driver should prepare for, and then execute.

This visual information may be displayed on self-contained CRT or LCD units mounted in the vehicle, or projected onto the windshield as a 2-dimensional holograph (i.e., "Heads-up display") for motorist

information while driving. The visual displays may also be augmented with audio messages such as a synthesized voice to give guidance instructions.

4.3 Communications and Data

Transmission of real-time information regarding traffic flow and roadway conditions to the in-vehicle device required an air-path communications medium. Examples are described below:

- VHF/UHF low frequency two-way radios (limited number of users)
- FM Side-Channel Transmission (central-vehicle)
- Infrared Beacons with Radio or direct-channel communications (vehicle-roadway), converted to trunk communications with Central facility.
- Television Spectrum-Vertical Blanking Interval, side-channel communications between allocated broadcast channel frequencies (central-vehicle)
- INRAD™ -Use of loop detectors's conductivity to serve as receivers and transmitters of information to vehicles with special radio receivers. Processing could be possible either through localized processing in field or by using existing two-way communications between field processor (e.g., Type 170 controller) and central site.

Use of infrared beacons was developed in Europe for operation of the Ali-Scout system, now undergoing testing in Michigan. To service in-vehicle systems, the ITS architecture should have the capability, through the central TID and appropriate data services, to output digital data in a format usable by driver information systems. As the quantity of system status data to be transmitted for each sampling interval will likely be enormous, the initial effort should be to transmit data of the most critical importance to the driver. This includes congestion data, incidents, and recommended diversion routes. This information can then be processed by the on-board computer in determining a best route.

Communications between the vehicle and a transportation management system is generally two-way-that is, not only does the system transmit data on traffic flow conditions to the on-board devices, the equipped vehicles may also transmit data on their individual speeds, travel times, frequency of stopping, etc. to the system for processing. In this manner, the equipped vehicles may function as traffic measurement probes. These probes will be of great assistance in calibrating detection data and derivation of operational Measures of Effectiveness.

5. CONTROL STRATEGIES

This functional area includes those management and control strategies needed to improve roadway network efficiency, to manage demand, and to enhance traveler safety, in conjunction with the Omaha Metropolitan Area goals and objectives. The ITS Architecture for the Omaha area potentially contains the following types of facilities:

- Freeways
- Surface Streets
 - “Smart Corridor”, Major arterial routes parallel to or crossing major freeways within a defined travel corridor.
 - “Smart Streets”, Surface routes of regional significance which carry high traffic volumes across.
 - Other Surface Streets-Those major arterials which are of local and regional significance, as well as roadways of local significance for circulation.
- Transit Service
 - Buses

The emphasis on central in ITS is related to roadways. Hence the bus component of Transit Services is considered as a part of the freeway and surface street traffic management, although it is also a unique element in terms of traveler information and public transportation user services.

5.1 Freeways

Freeway control strategies can be separated into two categories:

- Control of Entry Rate
- Management of Demand on Freeway

Entry control is accomplished through the use of ramp metering, as discussed in more detail below. Management of freeway demand is a broader area, and includes real-time strategies such as ramp metering and route guidance, as well as appropriate traveler information strategies. The use of policies and practices including roadway pricing and toll collection can also contribute to management of freeway operations.

5.1.1 Ramp Metering

Ramp meters consist of traffic signals on freeway on-ramps. The purpose of ramp metering is to control the rate at which vehicles enter the mainline freeway, such that downstream capacity is not exceeded. In turn, this allows the freeway to increase the volume carried at a higher speed.

Another benefit of ramp metering is its ability to break up platoons of vehicles that have been released from a nearby intersection. The mainline, even when operating near capacity, can accommodate merging vehicles one or two at a time. However, when groups (i.e., queues) of vehicles attempt to force their way into freeway traffic, turbulence and shockwaves are created, causing the mainline flow to breakdown. Reducing the turbulence in merge zones can also lead to a reduction in the sideswipe and rear-end type accidents that are associated with stop-and-go erratic traffic flow.

Ramp metering can serve other purposes, as well, including:

- To discourage drivers from using the freeway for very short trips. Ramp metering is more likely to divert short trips to the arterial streets rather than long trips because the time savings

resulting from improved freeway flow will be smaller (or non-existent) for short trips as compared to longer trips.

- To provide incentives for bus ridership and carpooling by allowing HOVs to bypass the ramp meter. Typically, the time savings is one to three minutes.

In essence, ramp metering redistributes the freeway demand over time-storing any excess demand on the ramp, instead of on the freeway in the form of stop-and-go traffic. While this mode of control is used primarily to reduce the impacts of recurring congestion during peak traffic periods, ramp metering can also be implemented to combat incident-related congestion. For example, meters upstream of the incident area would operate at low metering rates, limited the number of vehicles entering the freeway. Using surface-street CMS and other driver information devices, entering vehicles would be diverted to on-ramps downstream of the incident. These downstream on-ramps would operate with relaxed metering rates (or no metering) in order to handle the increased demand.

Control modes can range from pre-timed (i.e., fixed release rates based on a pre-set schedule) to local traffic responsive (i.e., rate is calculated in response to traffic flows for adjoining mainline detectors) to system-wide control, which looks at an entire corridor and provides more equitable metering rates across the corridor. With the latter, this assures that no one meter is unduly restrictive (this mitigates potential queues which back into the surface street).

HOV bypass lanes are used at specific ramps to provide a travel time for use of carpools, vanpools and buses, generally through leaving the bypass lane unmeted. As an alternative, if HOV volumes increase substantially, they can be metered also, but at a more favorable rate than for single-occupancy vehicles.

5.1.2 Routing Strategies

The management of freeway congestion involves development of a combination of strategies. In particular, major incidents cause a natural diversion of traffic off the freeway system, which in turn creates difficulties for jurisdictions operating the traffic control systems along the surface streets. This is an area which requires an extensive amount of interagency coordination and operations planning activities, such that an appropriate set of response can be set aside for different types of incidents or for specific events. These proper responses are done on a coordinated basis. As this can be difficult with multiple agencies and with the staffing levels available, real-time building and implementation of response plans requires some degree of automation. This can be done through the use of Expert Systems.

Depending on the nature of an incident or event, and the magnitude of traffic congestion, it may be necessary to implement alternate route plans. Regional diversion is often needed to direct traffic away from the general area of congestion (e.g., as may be caused by an incident), reducing overall traffic demand approaching the site.

Local diversion routes are merely relief valves for congested freeway traffic in the immediate vicinity of the incident site, and cannot be expected to completely solve the congestion problem. However, advanced planning and effective implementation can increase local alternate route capacity, and save many hours of motorist delay. Local diversion routes may be developed for nearly every interchange-to-interchange segment of the freeway network and for all possible directions, including complete closures.

Proper operation of the surface streets is critical to the successful operation of local route diversion. Items which must be addressed include:

- **Traveler Information**-Travelers must be informed of the desirability or, in the case of a freeway closure, the necessity of diverting. Diversion information can be provided to motorists on the freeway via changeable message signs, highway advisory radio, and media reports.
- **Motorist Guidance**-Once motorists have been diverted from the freeway, it is crucial that they be provided positive guidance throughout the surface street network, directing them back onto the freeway at the appropriate ramp. Trailblazer signs can be installed along the alternate route whenever diversion is implemented. A possible sign message for general use would simply read “DETOUR” with an arrow indicating the direction to follow (i.e., right, left, or straight). Velcro-backed arrows could be employed to allow a single sign to be used for any direction of travel; and roadway symbols (e.g., Interstate shield, state route) could also be included. The signs may be a fabric or plastic material, with collapsible stands, for installation. These signs may be included in police or transportation agency vehicles; or if a diversion route is frequently used, the signs and stands may be stored in controller cabinets along the route (assuming that space is available). Police officers are often stationed at key intersections. Not only does this provide additional route guidance, but also enhances motorists safety along the diversion route.
- **Signal Timing**- Whenever diversion routing is implemented, the timing of the signals on the surface streets should be changed to accommodate the new traffic demands.
- **Congestion**-There is the possibility of “over-diverting”, thereby overloading the surface streets. If traveler information sources direct motorists to divert, and drivers find the alternate route is congested, then the reliability and credibility of future information may be questioned by the motorists. Monitoring the traffic flow on the surface streets is therefore an important part of diversion route implementation.

5.1.3 Congestion Prediction

At present, traffic management systems initiate actions after the roadway has already become congested. In the future, systems might predict when and where congestion will take place, and then implement steps to prevent the predicted congestion from occurring—for example, informing drivers and soon-to-be-travelers of alternate routes or alternate modes, advising them to delay trips, diversion, and modifying control strategies such as traffic signal timings and ramp metering rates. Including this “congestion prediction” capability into ITS-based systems will require research into new traffic assignment and corridor optimization models such that the system can anticipate where congestion will occur, and then evaluate the effects that various strategies will have on travel patterns and corridor operations. AVI and AVL technology should prove very useful in this regard, by providing current origin-destination data, and providing real-time information for calibrating the optimization models and for evaluating the effectiveness of the resulting traffic management strategies.

5.1.4 Freeway Incident Management

Freeway Service Patrols (FSP)

The FSP addresses many of the incident management elements. The time required to detect an incident may be reduced in some cases-the number of incidents affected and the time savings being dependent upon the frequency of the service patrols. Incident verification may also be enhanced because of the direct contact in the field. Most important, freeway service patrols can dramatically reduce the incident response and clearance time because the service provider is immediately on the scene, rather than appearing several minutes (or longer) after the initial call has been placed.

Freeway service patrols have proven to be one of the most effective strategies for reducing the delay and secondary accidents associated with incident-induced congestion. While the investment in equipment, materials, and labor can be significant, the services and time savings to motorists usually far exceeds these costs.

5.2 Surface Streets

5.2.1 Types of Signal Systems

The predominant type of signal systems in the Omaha area today are closed-loop systems. Development of microprocessor-based signal system components both for central and field elements will likely result in additional **changes** to signal system operators and configurations. The nature of the ITS Architecture will be to accommodate all types of signal systems. To do this, the appropriate data for signal status and traffic flow used for signal system operations must be made available to the information network.

5.2.2 Adaptive Control

SCOOT (Split, Cycle and Offset Optimization Technique)

Fully adaptive control creates fully responsive, on-line traffic control systems. An example is SCOOT (Split, Cycle, and Offset Optimization Technique), developed by the UK Transport and Road Research Laboratory. SCOOT is demand-responsive and adjusts to the cycle time, phase splits and offsets in accordance with an on-line optimization process. Short-term demand fluctuation information supplied by vehicle detectors in advance of each intersection is input to a traffic model. The model predicts the total delay and stops caused by the signal timings, and a signal optimizer adjusts the timings to minimize delay and number of stops. SCOOT operates small groups of intersections on a common cycle length and makes frequent, small modifications to the signal timings according to short-term demand fluctuations. It provides for continuous automated on-line timing plan updating, thus eliminating the need for off-line updating. It measures traffic flows, calculates flow profiles, predicts vehicle arrivals at stop lines, and estimates queue lengths.

The central computer performs all detector data processing and signal timing computations and provides signal timing information to the local controller at each phase change. The detectors used by SCOOT are inductive loops installed at the upstream end of each network link typically about 15 meters past the intersection. These may span a maximum of two lanes per detector and generally measure two meters in the travel direction. With a significant number of traffic sinks and sources along a link or other physical anomalies, a detector further downstream may be required.

Based on detector measurements upstream of the intersection, the SCOOT traffic model computes the cyclic flow profile for every traffic link every four seconds. SCOOT projects these profiles to the downstream intersection using the TRANSYT dispersion model. SCOOT contains provisions for weighting capabilities in the signal optimizers to give preference to specific links or routes. Table 9 summarizes the SCOOT optimization process. Recent additions to SCOOT have enhanced its performance under congestion and saturation conditions. Table 10 describes the enhanced SCOOT features.

TABLE 9
SCOOT Optimization Process

Timing Parameter	Process
Offset	<p>Attempts to minimize maximum degree of saturation on a phase</p> <p>A few seconds before every phase, SCOOT determines whether it is better to:</p> <ul style="list-style-type: none"> · Advance or retard the scheduled change by up to 4 seconds, or · Leave it unaltered.
Split	<p>Once per cycle, SCOOT determines whether performance index (PI) can be improved by reducing or increasing each offset by 4 seconds. The PI is usually a weighted sum of stops and delays.</p>
Cycle	<p>SCOOT varies the cycle time by a few seconds every few minutes to try, if possible, to keep the maximum degree of saturation below 90% on the most heavily loaded phase.</p>

TABLE 10

Enhanced SCOOT Features

Feature	Description
Congestion Offsets	Under congestion conditions, the best offset may facilitate a particular movement (to prevent spillback across an intersection or for other reasons). Under congestion situations , SCOOT provides congestion offsets which replace with a specially designed offset the criterion for optimization the PI. information from another link may also be used to implement offsets under congestion conditions.
Gating Logic	Gated links are designated to store queues which would otherwise block bottleneck links. Thus, green time can be reduced on a gated link as a function of saturation on a remote bottleneck link.
Automatic Calibration of Saturation Occupancy	Early versions of SCOOT required the system operator to supply the appropriate value of saturation occupancy . The latest version of SCOOT provides this capability automatically, which: <ul style="list-style-type: none"> - Eliminates a calibration effort, and - Improves responsivity to the real time changes of this value as a function of temporary conditions.

SCATS (Sydney Coordination Adaptive Traffic System)

SCATS was developed by City of Sydney and is distributed by AWA Systems in North America. It is a fully traffic responsive traffic control system. It provides the following functions:

- Requires detector loops in each lane for all intersections
- Requires SCATS controller at intersections
- Subsystem (up to 10 Intersections)/system (up to 6 subsystems)

The following operations are provided by SCATS:

- Detects vehicles by lane
- Adjusts splits/offsets/cycle lengths for each subsystem
- Internal background offset plan
- Marriage/divorce (external offset plans to link adjacent subsystems)

SCATS uses two levels of control: strategic and tactical. Strategic control determines suitable signal timings for the areas and sub-areas based on average prevailing traffic conditions. Tactical control refers to control at the individual interaction level. SCATS computations distribute between a computer at the traffic operations center and the field controller. Implementation in the US therefore requires special adaptation of NEMA and Model 170 controllers to incorporate the SCATS field processing functions.

SCATS uses inductive loop detectors, or those that can simulate a loop detector's output. Detectors are located at, or near, the stop line. Typically strategic links are identified and strategic detectors are installed, normally 4.5 meters (about 15 feet) long, in all lanes. Occasionally, additional strategic

detectors are installed upstream to detect queuing. At the local control level, tactical detectors normally the same type as strategic detectors, may be located upstream of the stop line.

SCATS requires strategic detectors on all links approaching major intersections and on any links immediately upstream of a major installation. In general, tactical detectors identify turning movements on minor approaches. Table 11 describes the functions at strategic and tactical control levels.

TABLE 11
SCATS Control Levels

Feature	Description
Strategic	<ul style="list-style-type: none"> · A number of signals (from 1 to 10) group together to form a subsystem - Up to 64 subsystems can link together for control by a regional computer - Each traffic signal in a subsystem shares a common cycle time, updated every cycle to maintain the degree of saturation around 0.9 (or a user definable parameter) on the lane with the greatest degree of saturation. Degree of saturation corresponds to an occupancy value measured by the detector. · Cycle time can normally vary up to six seconds each cycle but this limit increases to nine seconds when a trend is recognized - Phase splits vary up to 4% of cycle time each cycle to maintain equal degrees of saturation on competing approaches, thus minimizing delay. · Offsets selected for each subsystem (i.e., offsets between intersections within the subsystem) and between subsystems linked together.
Tactical	<ul style="list-style-type: none"> · Operates under the strategic umbrella provided by the regional computer. - Provides local flexibility to meet cycle variation in demand at each intersection. For example, any phase (except the main street phase) may be: <ul style="list-style-type: none"> omitted terminated earlier extended · Time saved during the cycle as a result of other plans terminating early or being skipped may be: <ul style="list-style-type: none"> used by subsequent phases - added to the main phase to maintain each local controller at the system cycle length

RT-TRACS (Real Time Traffic Adaptive Control System)

A new RT-TRACS project represents the first major attempt to develop a traffic responsive system control algorithm in the United States since the UTCs projects of the 1970's. This study, to develop a prototype real-time, traffic adaptive signal control system suitable for use in an ITS environment by 1997, is the first of three studies which will eventually develop five prototypes for laboratory evaluation, from which one will be selected for further development and field evaluation by 1997. This study encompasses the first

stage of a long term effort. A single, major contract was awarded to a consortium composed of state and local DOT's, private industry, and academia. Currently, the contractor has prepared preliminary functional design specifications for the system. Review of state-of-the-art signal system technologies for applicability to the development of the real-time traffic adaptive control system is being performed. Modifications to off-line optimization software needed to support real-time control will be investigated.

In addition to real-time control, RT-TRACS will incorporate all applicable features of existing systems, and also new architectures and technologies. Furthermore, it promises significantly greater cost-effectiveness than system currently available. This control strategy will also significantly improve on currently used traffic signal control concepts to provide:

- The best possible signal timings in all types of traffic situations, and
- Updated signal timings with limited effort.

In this context, RT-TRACS will include as its goals and objectives the ability to:

- Control the entire spectrum of traffic conditions, including undersaturated and oversaturated flow, and congestion management in real-time.
- Recognize the possible requirements for different types of traffic control strategies, and implement the strategy most appropriate for existing demand characteristics and local area/system-wide objectives.
- Accept different measures of effectiveness based on the requirements of the local traffic engineer and the traffic flow/network situation.
- Influence traffic demand through the use of various signal timing concepts, including metering, variable phasing, reversible lanes, and phase skipping.
- Disseminate information collected and/or calculated by the system to other control systems (e.g., ITS), the media, and other government agencies.
- Interface with other transportation control systems for effective system/corridor management, such as freeway metering systems, and for effective people movement, such as transit vehicle control systems (including buses and Light Rail Vehicles).
- Monitor itself to permit the implementation of truly intelligent and effective adaptive traffic control, that adjusts its operation based on the success or failure of past performance.
- Adapt to the needs of all types of jurisdictions, from small isolated cities to large urban areas.
- Control costs through flexible deployment strategies, so that initial start-up costs and annual maintenance costs to not preclude installation and continued operation of the system.

Adaptive traffic control systems provide additional benefits over fixed-time systems by responding to:

- Flow variations within a signal plan period, and
- Daily and seasonal fluctuations.

Adaptive systems also adjust automatically to long-term changes in traffic conditions, avoiding the “aging” disbenefits which occur when agencies do not regularly update fixed-time signal plans. Specific benefits of adaptive traffic control will provide greatest with:

- Short links,
- High flows, and
- Significant flow variations in a signal plan period.

Of these factors, traffic flow volume dominates in determining overall benefit levels. As urban flow levels increase, the benefits of adaptive techniques will become even more significant.

Future traffic signal control systems may utilize a fourth generation control strategy. In addition to providing a quicker response to rapid changes in traffic flow conditions, 4 GC systems may also perform short-term forecasting, based initially on historical experience, and ultimately on real-time origin-destination estimation.

6. DATA PROCESSING

The following elements of information processing, including functional requirements and potential solutions, are described below:

- Database/Geographic Information Systems
- Networking
- Open Systems and User Interface
- Decision Support

In ITS, the variety of operational components require a number of stand-alone subsystems. The technology of traffic management has moved in recent years toward distribution of intelligence between central and field hardware elements through the use of microprocessors. From a central operation viewpoint, a potential problem is the need to control and monitor different elements simultaneously. The monitoring of dedicated subsystems on a simultaneous basis is a labor-intensive task if separate terminals are required. Likewise, the development of integrated traffic management strategies requires the use of some means to simultaneously operate multiple subsystems.

6.1 Databases/Geographic Information Systems

For a dynamic operational ITS database in the Omaha area, the following functions will be required:

- Collection of data from many systems
- Dissemination of data to many systems
- Access to data from multiple agencies and the public
- Ability to transmit information to in-vehicle devices via appropriate data servers

Two types of database structures can be considered:

- **Record-based structure**--Deals with elements as quantities and records.
- **Geographic-based structure**--Looks at elements utilizing spatial relationships. Records and characteristics are defined as a function of location coordinates on a particular surface.

Transportation information is spatial in nature. When accessing a multitude of data and information ranging from traffic conditions for specific locations to status for specific field devices, the variety of information requirements indicate the need to show these items in some graphical sense. A transportation system can be modeled as nodes, links, and attributes in a two or three dimensional space. Events occur within the framework of this model at a node (an accident, a signal location), along a link (vehicle volumes, available capacity), or within a buffer of the link (e.g., number of people living within 250 feet of a highway). Historically, such data has been incorporated into multiple information systems essentially unrelated to one another.

With development of Geographic Information System (GIS), the various static data and dynamic information can be treated as information layers for specific spatial coordinated. A GIS may range from a simple two-dimensional display (bit-mapped graphics) to a topological GIS which allows graphical

displays based on actual topography, and which have several different layers of information, plus the capability for complex data analysis along the network.

For ITS, this can provide a framework for the data to be processed in real time. On the simplest level, this involves display of one or more parameters graphically, as is required to show real-time traffic status on a map using defined color codes. On a higher level, it involves analyzing a series of data (i.e., estimating travel times between two points selected on the map). At its most complex level, the GIS could have the capability of comparing multiple sets of data meeting various constraints, and then selecting a “path of least resistance” along with associated strategies for implementation. For example, a series of real-time information could be used by a GIS-based Expert Systems to select an appropriate incident or congestion response strategy.

For any ITS architecture with some method of central dissemination or monitoring, a GIS database is recommended as the central collection and dissemination mechanism, with other system (i.e., Expert Systems, control subsystems) accessing the information and performing spatial comparisons. The GIS, through its spatial layering technology, allows viewers to collect and categorize travel information, interpret and analyze the information, aid in problem resolution, and integrate spatially-related data from other agencies for interagency analysis purposes.

Multiple organizations could have access to the central GIS through a “base map” by which updates can be incorporated and entered into the system. Some of the benefits of a GIS to Advanced Traffic Management Systems (ATMS) are:

- User can query ATMS in a spatial manner
- Geographically organized information can be shared between agencies, aiding interagency analysis of transportation
- Facilities management functions incorporated into an ATMS can facilitate the management of remote ATMS components.

The GIS must be capable of spatial and temporal (time-comparison) analysis of real-time data in order to predict traffic flow information in conjunction with developing routing and response strategies, as well as navigation and control processing.

Some of the basic functions for GIS, as related to ATMS projects, are:

- Route and Flow Optimization
- Route Selection and Navigation
- Tracking and Monitoring
- Surface and Subsurface Assessment
- Resource Allocation
- Map and Chart Publishing
- Geographic Data Collection and Production
- Facility and Asset Inventory
- Site Location Planning

6.2 Networking

The multi-jurisdictional nature of the Omaha area ITS Architecture calls for the coordination of operational strategies and providing information from multiple sources which can then be disseminated using common formats. The following are possible data exchange scenarios and dissemination functions in the ITS Architecture:

- Sharing of data and video images between Traffic Management Centers (TMC) requiring coordination of signal timing or operational strategies to handle recurring congestion for critical corridors.
- Sharing of data and video between a local TMC and the regional TMIC for coordination of freeway and surface street operations strategies in response to recurrent congestion or frequent event traffic.
- Correlation of data from various sources and dissemination via various methods, including media links, direct display via cable TV or public kiosks, links to in-vehicle displays.
- Correlation of data from dynamic development or selection of multi-agency response plans, including alternate routings.

Three types of links are possible for an interconnected ITS Architecture:

- Direct agency-to-agency intertie (dedicated)
- Dedicated tie-in from all agencies to central data clearinghouse
- Dial-up connections to any elements in the system

For continuous operation of system elements, dedicated links are recommended, with dial-up used by system users or interested parties when necessary to access specific information.

Operation of the ITS Architecture requires the use of networking strategies to provide full access between system elements, including the ability to share resources (e.g., local agency utilizing information from a NDOR CCTV camera), as well as the ability to access to data from other systems. The nature of network structure is that digital communications between devices is accomplished based on standard protocols. A full metropolitan area system with standard interfaces between all elements is a Wide-Area Network (WAN), while a system at the local level with different elements using a standard interface is a Local Area Network (LAN). A typical network interface configuration for LAN's and WAN's is EtherNet.

Likewise, the latest trends in the area of "stand-alone" agency operations (within a TMC or TOC) have been moving toward distribution of processing capabilities. Separate subsystems (e.g., CMS, CCTV, signal system) are responsible for communication to microprocessors in the field (such as Type 170 controllers). The microprocessors themselves have some level of intelligence, including storage of messages, automatic dimming capability and the ability of displaying a message either upon the command of the subsystem computer or based on a traffic-responsive algorithm located at the controller itself.

The interface between different subsystems is accomplished by using a LAN, which utilized a standard protocol (e.g., serial, EtherNet) for communications between devices. The concepts of local area networks

and wide area networks allows for maximum flexibility and distribution of processing, and thus allows operations to be less restricted by the hardware configuration.

6.3 Open System Design Considerations

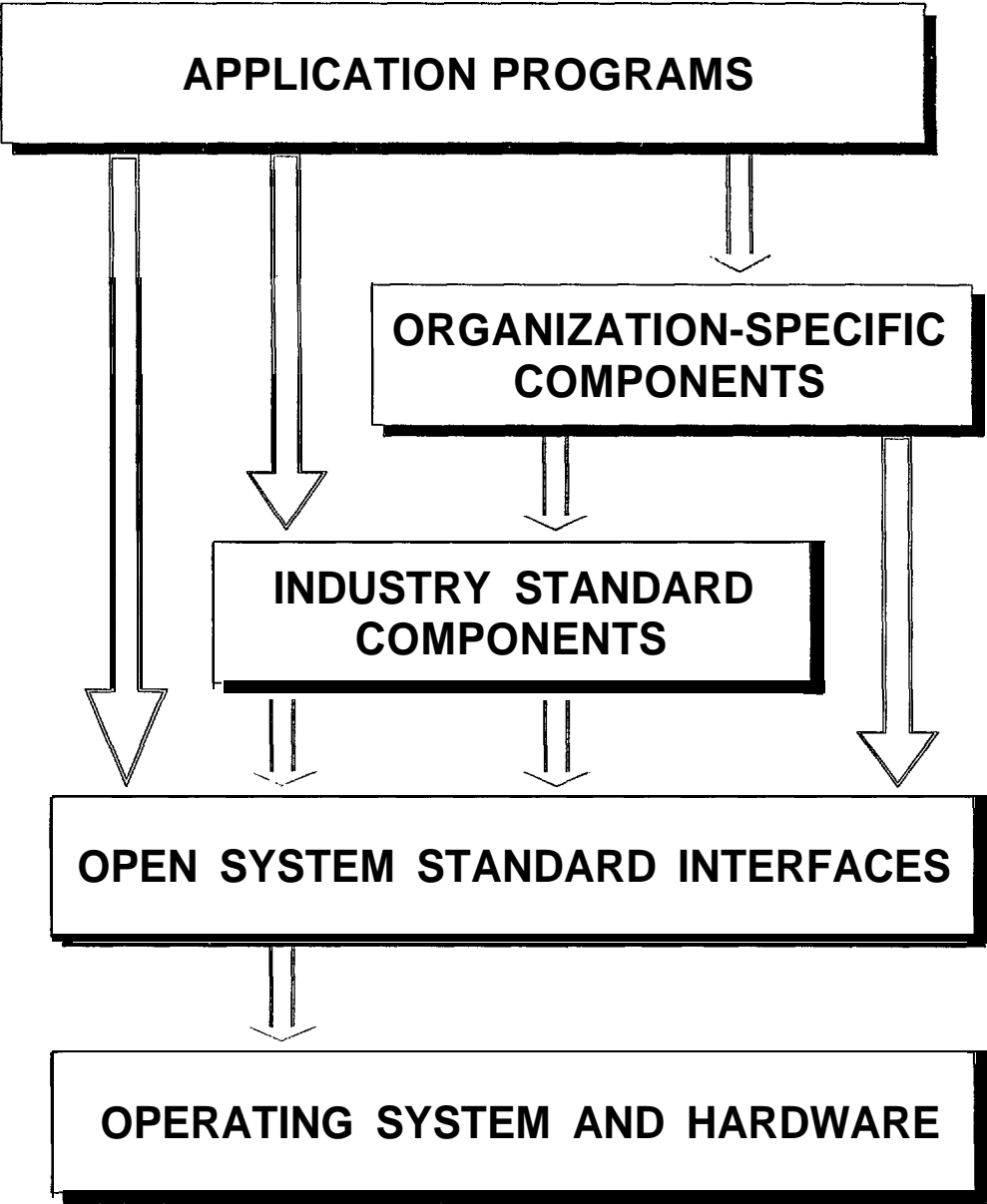
The systems designed to service the Omaha Metropolitan area ITS Network must take full advantage of the latest software design techniques. Given the necessary functional requirements, the software design is to allow for a maximum level of flexibility and expandability.

The nature of any multi-jurisdictional effort is that a variety of hardware and software platforms will be involved. Many systems may already exist and must be integrated into a unified system. Since many of these systems may have evolved independently, each will have its own special features and characteristics. With future expansion, more diversity may be added to the system, as different platforms may prove to be more appropriate or cost-effective for various tasks. It is thus very reasonable to expect the ITS network to be very heterogeneous, possibly including hardware from several vendors. Operating systems may include VMS, UNIX, DOS, MS-Windows, and OS/2, as well as others. It is essential that all of the ITS system software be designed specifically for an Open System Environment (OSE).

Open Systems: An Overview

The Portable Operating System Interface (Posix) Open System Environment (OSE) is a set of standards which is being assembled by Working Group 1003.0 of the IEEE Technical Committee on Operating Systems (TCOS). The Posix OSE standards include both IEEE Posix standards as well as standards from ANSI and ISO.

The Posix OSE standards define two types of standard interfaces: the Application Program Interface (API) and the External Environmental Interface (EEI). APIs are procedure calls made to the platform on which an application is running. These calls may interact with the operating system, system utilities, or other applications. In an ITS Network, these calls might include database transactions and file transactions. EEIs are connected to the external environment, which is often defined to include external devices such as printers, graphical displays, disks, and networks. In the ITS Network environment, the external environment will also include controllers, detectors, changeable message signs, CCTV cameras, and other hardware. As integrated multi-jurisdictional elements are developed, the use of the Posix Open Systems Architecture modes (illustrated in Figure 8) is essential.



POSIX Open System Architecture

Figure 8

The Posix OSE standards address four general areas of service: system services, communication services, information services, and human-computer interaction services. The goal of the Posix Open System Architecture is to isolate the application from the peculiarities of the underlying operating system, as shown in Figure 8. The layered approach allows the introduction of software packages that are specific to the system or application, such as would be required in the ITS Network. However, it is important to note that many of the specifications are under development for OSE architecture.

Figure 9 shows the reference model for Open Systems interconnection (OSI) and the currently available interfaces for network communications. The lower level interfaces provide very little abstraction from the details of communications and contain the most system-specific code. NetBIOS is at the Session Layer, IPX is at the network layer, and SPX is at the session layer. Sockets, while existing at the session layer, provide a little more abstraction than the previous three interfaces, and thus lies closer to the application layer. NetBIOS, SPX, and IPX were all spawned from the PC environment and find the most support in that area. Sockets were originated in the UNIX environment and have been implemented across virtually all platforms.

Currently, many of the interfaces are not supported across a wide range of platforms. The most widely supported communication mechanisms of those mentioned above is the TCP/IP Socket. The widespread use of TCP/IP Socket ensures that it will be supported as a more suitable interface is developed in the future.

Another organization which should be considered in the Open Systems area is the Open Software Foundation (OSF). They have developed the Distributed Computer Environmental (DCE) which addressed four problems: (1) the diversity of operating environments, (2) the large number of interconnected system, (3) security, and (4) the need to create new network applications. DCE is compliant with OSI and Posix standards and specifies interfaces and protocols for a network computing environment. The networking facilities, for example, will operate over many network protocols and will have the bit and byte ordering tasks that are a part of data conversation between hardware platforms. DCE is also gaining support from major software vendors, and DCS will be available as a part of the operating system software under UNIX, VMS, MVS, MS-Windows, and others. OSF is also the source of OSF/Motif, which has become the dominant toolkit for X Window-based graphical user interface development.

The major benefits of moving toward Open Systems Architecture are accelerated application development and lower maintenance costs.

Layer

7

APPLICATION

6

PRESENTATION

5

SESSION

4

TRANSPORT

3

NETWORK

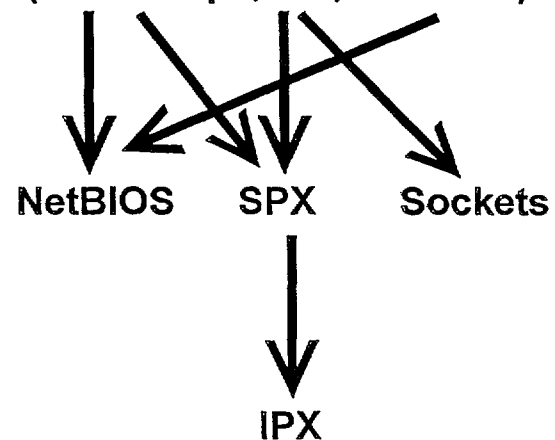
2

DATA LINK

1

PHYSICAL

Application Layer Interfaces
(NamedPipe, TLI, Mail Slot)



*Reference Model for
Open Interconnection (OSI)*

Figure 9

Open Systems Design Issues**1. Open System Environment: System Services**

Software developed should be portable across operating systems and compilers. A variety of operating systems may be used at the TOC, TMCs and other system facilities.

The System Services category includes facilities provided by the programming language and the operating system. Standards are already in wide use in the area of programming languages. An example is the ANSI standard for the C Programming Language (X3.159-1989). Many C compilers now support "ANSI C". For other languages, specifications exist which describe the features of the language. The C++ language is described by specifications created by AT&T, the originator of the language. Many compilers support the AT&T version 2.0 specification, and some support the Version 2.1 specifications. In this case, it will be necessary to identify the minimum desired level of functionality and the corresponding specification, and identify compilers which are compliant with that specification. It will be necessary to identify appropriate compilers across a variety of platforms.

In the arena of operating system functions, the Posix kernel standard (1003.1) specifies language bindings for C. Similar bindings for Ada and Fortran will soon be available, and a set of language independent bindings are under development by Posix working groups. These binding specifications provide a common interface to operating system functions such as file input and output and process control. Thus, the use of such functions should be portable across a variety of operating systems.

Posix support is becoming available from many of the major computer hardware and software vendors, including IBM, Digital, Sun, AT&T, and Microsoft. It should be feasible to direct software development to adhere to the Posix kernel standards. Since the C++ language provides C language binding facilities, these facilities may also be utilized in the C++ environment.

Software for the ITS Network should be developed using the Posix standard kernel interface to ensure portability across platforms. The language of choice is C++, and a uniform set of compilers need to be identified for a variety of environments.

2. Open System Environment: Communication Services

In a distributed and networked environment, communication services play an important role in the gathering and dissemination of data among client and server processes. Communication services must serve all of the platforms in the ITS Network, and the communications software must be portable across the platforms.

Typical communication services for a networked environmental include facilities for file transfer, network file access, remote procedure calls, protocol-independent network access, and data representation. Standards for many of these facilities are under development.

Several common networking standards have been developed, including the IBM System Network Architecture (SNA), the Digital Equipment Corporation DECnet, and the Department of Defense (DOD) Military Standard Protocols. The DOD Protocols have been in use in use for many years on ARPANET and the Internet. The facilities include TCP/IP (Transmission Control Protocol/Internet Protocol), FTP

(File Transfer Protocol), SMTP (Simple Mail Transfer Protocol), and the TELNET Protocol as shown on Figure 10. These standards are supported across many platforms, in many programming languages, and by many off-the-shelf software packages. The DOD has committed to migrating from the DOD standard protocols to international standards. Considering the large base of equipment supported by the DOD, their protocols are expected to be supported well into the future.

The ITS Network should be capable of supporting the DOD communication protocols, including TCP/IP, FTP, and TELNET. This will not only provide accessibility across many platforms, but it will also enable the use of many available communications packages.

3. Open System Environment: Information Services

The ITS Network will require use of Database Management Systems in a heterogeneous networked environment. Consistent interfaces between networked clients and servers will be required, allowing clients and servers to exist on different platforms. Data interchange services will be required to handle the exchange of data between different platforms.

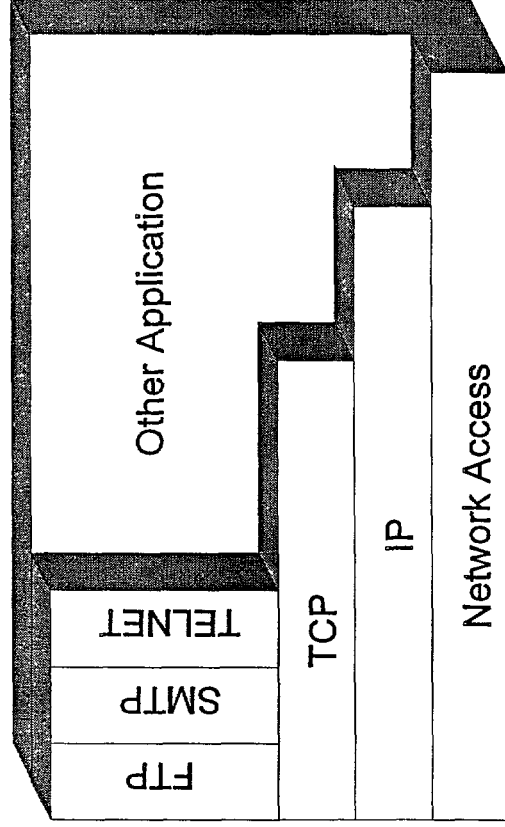
Basic database services include the ability to access data and to perform searches based on potentially complex set of conditions. Other operations include inserting, deleting, and updating records. The Database Management System must also provide facilities to ensure data integrity. Facilities must also exist to translate between data representation across platforms. As an example, the representation for a double precision floating point number of a Digital VAX computer is very different from that on a Sun workstation, and the database services must account for those differences when clients and services communicate.

One of the standards in the Posix OSE information services area is the SQL standard (ISO 9075:1982). Many database products support the standard SQL interface. A variety of other products include the SQL interface to allow data to be imported from databases.

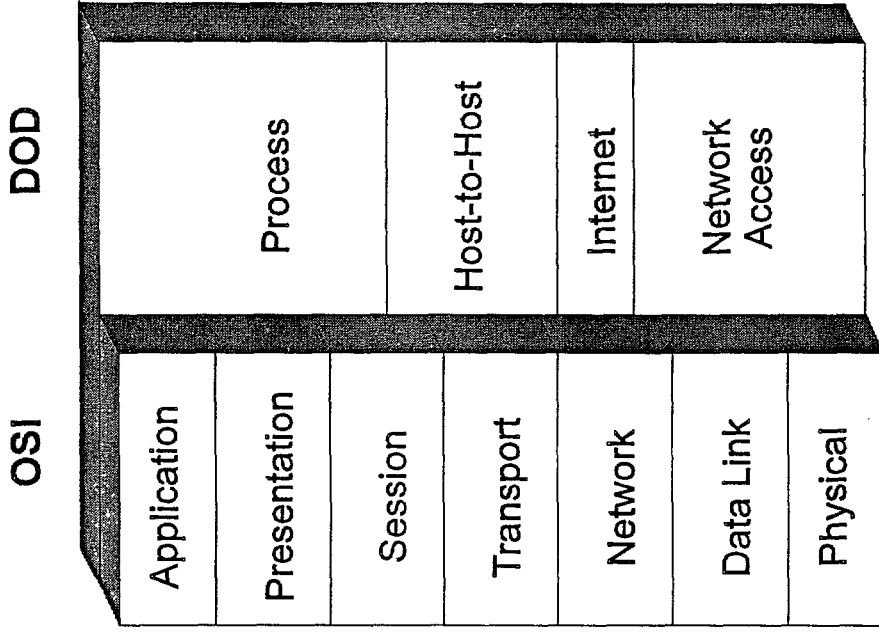
Data interchange standards are under development for data format protocols. In addition, because graphical data will play an important role in the ITS Network, the Computer Graphics Metafile (ANSI X3.122-1986) may be important, because it provides a means for storing and exchanging graphical data. As standards are developed, they will be examined for inclusion into the system.

The OSF Distributed Computing Environment (DCE) provides facilities for data conversion between platforms. Several vendors are currently porting DCE software to their operating systems, and DCE should be available under UNIX, VMS, MVS, and MS-Windows in the near future. Use of DCE should be considered as a possible approach to the data interchange problem.

Omaha Metropolitan Area ITS EDP Study



DOD Protocol Interfaces



Comparison of OSI and DOD Communications Architecture

DOD Network Protocols

Figure 10

SQL is recommended for adoption as the standard interface for all of the databases in the ITS Network. This should enable the use of many variable software packages for database interaction. All SQL commands and data may be expressed as ASCII character strings. Thus, a client/server pair could be constructed to build the strings, transmit them across the network, feed the strings to the SQL user interface, accept the returned data, and transmit the data back to the client in string form. The string format, while somewhat crude, eliminates the issues of bit and byte ordering in most cases.

4. ***Open System Environment: Human-Computer Interaction***

With the variety of devices required for modern traffic management systems, combined with the necessity to integrate the operations of these elements, there are not only concurrent tasks required, but also the need to monitor these simultaneously. With the staffing and space limitations of government agencies, this can be highly difficult if multiple, dedicated terminals are used. Likewise, in coordinating traffic data from a local system as well as that from another agency's system, it is necessary to be able to perform these tasks without interrupting other operations, including logging of information and carrying out routine system tasks. Hence, the requirements of the User Interface are for the ability to perform multiple tasks and provide multiple user "windows" for access by the System Operator to subsystem control facilities, as well as information (usually graphically presented) from other agency systems.

With the multiple system algorithms, applications, operating systems, and data sources which must be supported, a multi-tasking environment is essential. Such an environment is found in a Graphical User Interface (GUI) with full multi-tasking capabilities. A product such as Windows provides a GUI by basically acting as an overlay for the MS-DOS operating system, which does not allow for true multi-tasking for continuous processes. True multi-tasking GUI operating systems include the upcoming Windows NT, OS/2 (full multi-tasking plus graphical interface), and the Macintosh Operating System, as well as X-Windows, which is a GUI that has become the de facto standard with the multi-tasking UNIX Operating System and network environments.

The use of multi-tasking GUI in conjunction with a GIS is underway at this time. Referred to as a Geo-Graphical User Interface, the overall system performance can be improved through the use of spatially related elements. The use of object-oriented programming strategies provides these capabilities in the system. A key benefit of this interface is that multiple-linked applications and graphical, textual, and video images may be displayed on an integrated ATMS workstation for an interactive, command, control, and monitoring environment.

The Graphical User Interface (GUI) should provide display and selection features which are uniform across platforms. The interface should use a standard protocol between application programs and display terminals. The interface should also conform to human factors standards.

The evolution of the GUI enables the integration of a number of different user services into one common control interface. Key attributes of a GUI applied to the ITS Architecture are:

1. **Presentation of data in text and graphical formats.** This allows status information to be conveyed by color and graphical representation for ease of assimilation.

2. **Accessing system information through a map of the system area.** Such as using a mouse to point at a map where an icon shows the element location; “clicking” selects the element and retrieves current data regarding the element. Zooming in and out of the map allows for the view of larger areas but less detail or smaller areas with more detail.
3. **Multi-tasking.** Tasks run in “windows”; concurrent windows can be opened for carrying on parallel activities.

6.4 Decision Support

For any incident management or traffic management strategy which affects multiple agencies, a series of decisions must be made which determine the goals of that strategy, and the various actions that must be taken for the corridor in question. The decision-making process can be facilitated through use of a decision support mechanism, which accesses the full range of policy information (static information) and compares it with real-time traffic information. The quick correlation of incident reports and observations can lead to a more rapid incident confirmation. This in turn allows a response strategy to be established more quickly. However, determining the best course of action, particularly as it involves a number of agencies, is highly dependent upon a good deal of professional judgment and experience.

Thus, the most useful decision support mechanism is a Knowledge-Based Expert System (KBES). An Expert System which correlates congestion or incident management can also be utilized to determine the appropriate strategies for various agencies to implement in coordination with their policies. Using a static database (the Rule Base), a number of strategies may be defined for the following:

- Traffic Management (response plans, including alternate routes, modifications to ramp meter rates, signal timings, CMS and HAR messages).
- Motorist Information (media information and other data to be transmitted to the public).
- Incident Management (appropriate contacts and procedures for more rapid removal of incidents).

The Rule Base is developed through an extensive process of operational planning, which for the Omaha Metropolitan area, would involve NDOR, Highway Patrol, plus numerous jurisdictions. Policies would be established for specific diversion routes, signal timing at key locations, CMS messages, and other operational concerns. Such information would be coded as rules, and would contain operational threshold values for various traffic measures which will identify themselves when a response is required.

The dynamic database (the Knowledge Base), which extracts real-time data from the appropriate traffic management systems across the ITS wide area network, provides the Expert System with the parameter values necessary to perform trade-off analyses and comparisons, and synthesize appropriate strategies and actions that are then presented to the various corridor agencies for approval. The recommendation could either be accepted in full by all the Agencies (i.e., System Operators) or modified based on additional real-time knowledge (i.e., weather, unscheduled special events) not ascertained by the Expert System. Based on this, the appropriate strategies are then sent automatically to the appropriate agency ATMS elements for implementation without the need for further Operator intervention. The Expert System also could

provide the means for conflict resolution between different agency policies or strategies which do not support one another. This is particularly valuable for adjoining agencies which have different policies concerning using a specific roadway in a response plan, or between a regional agency and local agencies.

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